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MM&T: TESTING OF ELECTRO-OPTIC COMPONENTS

Paul R. Ashley
Peter D. Poulsen
Science Applications, Incorporated
Huntsville, AL 35805

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U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809

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Current optical component testing methods were reviewed. Suggested optical testing procedures and standards related to production testing were presented. Optical transfer functions and related applications were reviewed. New approach to production testing of optical components including an analog OTF measurement was laboratory demonstrated.

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1. INTRODUCTION

This is the final report on the first phase of an Army sponsored investigation into the Testing of Electro-Optic Components. This first phase had as its objectives a reexamination of specification practices (Task 1) and an analysis of production oriented testing procedures suitable to Army weapons systems (Task 2). The second phase of the investigation is to extend the findings of the first two tasks to demonstration of the testing method to be recommended as part of Task 2. The second phase, an option exercisable by the Army pending successful results, would be based in large measure on the technique recommendations of Section 4 and the hardware recommendations of Section 5 of this report.

Section 2 will present a review of the findings of first phase study. Section 3 will discuss technical aspects of optical transfer measurements as suggested in this study for testing tactical optical assemblies. The technique already alluded to regarding Section 4 provides details of a specialized implementation of transfer function measurement particularly suited to the production-oriented testing of various Army systems. Section 5 details a specific implementation of the concept integrated with focal length, scattering and spectral measurement hardware.

During the course of study SAI had an opportunity to contact various Army program and laboratory offices. These contacts have led to several conclusions that were somewhat unexpected, as well as to an unexpected opportunity to make a fundamental contribution to the entire field of optical missile seekers.

2. REVIEW OF STUDY FINDINGS

The design of an optical system requires more than an understanding of the theories of geometric and physical optics. There is a technology of component and subsystems production that must be dealt with. Otherwise, the resultant optical system may well be inefficient, too expensive, low performance, or all three. The U.S. Army, in its absolute need for high performance and reliability, felt that it might be overspecifying, and perhaps incorrectly testing electro-optical devices. If so, it might well prove to be spending more money than required. Additionally, it might be forcing vendors to supply designs that were weight or size inefficient. Furthermore, it becomes a matter of suspicion that the optics, being the very front end of a seeker missile, should almost always be designed first, not last.

Once an optical system is decided upon, the spatial requirements and the component interrelationships are not very flexible. Unfortunately, it is not at all uncommon for project developments to let the optics take a back seat. Perhaps this is because optics is such an old field of science that it is taken for granted that it will not present the problems expected of aerodyamics and microelectronics. However, it should be pointed out that it is far simpler to modify a breadboard circuit to "tweek up" its temporal frequency response than it is to improve the spatial frequency performance of a lens or mirror.

2.1 MEANINGFUL SPECIFICATION PARAMETERS

One would hope that optical component and assembly specifications would be based on a clear cut understanding of what happens to overall system performance if some parameter is changed. In the case of an optically guided missile it would be hoped that the influence of increased scattering, for example, on the acquisition and accuracy of the seeker would be known. In fact, the investigations of this study showed it not so. As this circumstance became clearer during the program investigaitons, an avenue was sought by which such information might be obtained. In effect, it was found that the area of investigation needed to be extended from the area of concern initially proposed diagramatically by Figure 2-1 must be extended to be inclusive of all elements in the block diagram, not just those enclosed by the dashed line.

SENSOR SYSTEM CONSIDERATIONS

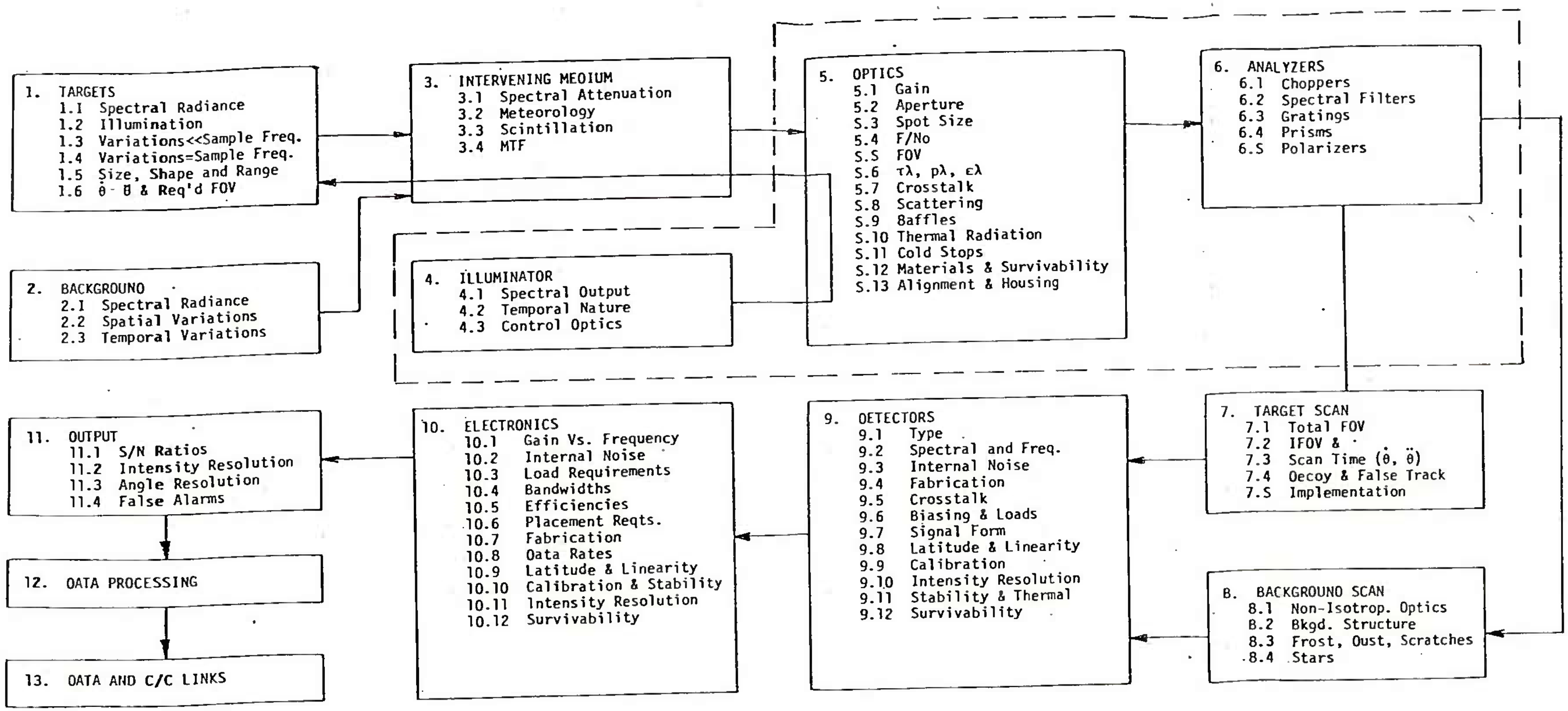

Figure 2.1 Sensor System Considerations

Discussions were undertaken with the U.S. Army Missile Command's Guidance and Control Directorate. In particular, the G&C facility for hardware-in-the-loop, captured sensor simulation of homing missile flights was visited. This facility is designed for low cost statistical analysis of miss distances for laser spot seeking missiles. A seeker head is strapped into a multiaxis motor driven gimbal and a laser spot is rear-projected onto a screen. Figure 2-2 shows the basic arrangement. Digital and analog computers are used to calculate aerodynamic effects and to cause the spot to displace and the gimbals to turn in simulation of the missile's closure on a target. At the end of a run, the miss distance is output. Large numbers of runs for various acquisition ranges and angles can be made at low cost. This allows compilation of statistically significant data.

It was suggested to the facility director that an optical seeker assembly be made available for modification to its optical components. These modifications would be made in a controlled manner and categorized by the automatic testing facility described later in Section 5. In this way a large amount of system performance data could be compiled by multiple runs of the sensor after each modification. The resultant data would be unprecedented and would, perhaps for the first time, lead to seeker component specification based on something other than educated guesswork.

At this writing, the G&C group seems ready to undertake the suggested program. However, as they point out, the key to long range success is the availability of an automatic optical testing system that does not require an experienced optician and a laboratory environment. Such a facility is, of course, the objective of the optical testing program.

2.2 RESULTS OF INDUSTRY INVESTIGATION OF SPECIFICATIONS

At the onset of the studies, concern arose over whether the techniques and criteria of specification were appropriate. The electro-optic community was openly criticizing the specifications as they were received from the Department of Defense. SAI investigated these complaints by reviewing published commentary, by talking with peers at symposia, and by visiting with government (U.S. Army, National Bureau of Standards) and commercial (Bell and Howell, Hewlett-Packard, Itek, Applied Technology) organizations. As a result of these

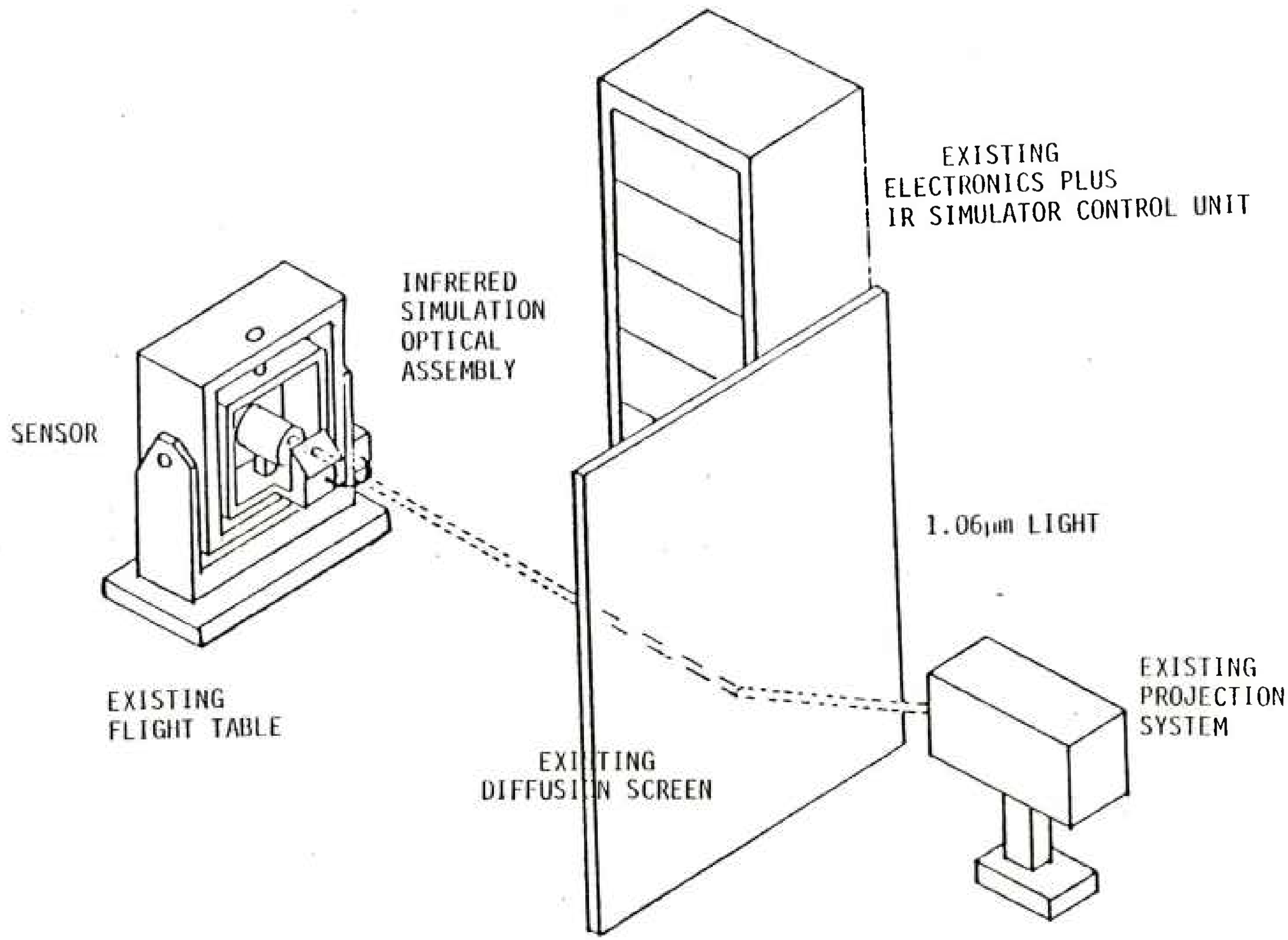

Figure 2.2 Hardware-in-the-Loop Captured Sensor Simulation

efforts, SAI concludes that the degree of concern expressed by the electro-optics community is perhaps exaggerated. It appears that the only largely justifiable complaint is that scratch and dig specifications are often imposed without consideration of their significance to system performance. Picatinny Arsenal is apparently trying to improve on the appropriateness of scratch and dig specification.

Nevertheless, it is extremely important to note that the lack of validity in community complaints by no means indicates that any validity is to be found in the typical component specifications when examined in light of system performance.

Project Offices strive for a pragmatic balance between cost, schedule, performance, and scientific possibilities. It is probably of value, by virtue of thoroughness, to collect a bibliography of specifications. Such a collection is being assembled under the parallel contract and substantiates SAI's conclusion that the U.S. Army Project Offices are not exercising either undue negligence or haphazard demands. Rather, they are operating on a best guess basis. Nevertheless, it is clear by way of discussion that production testing is generally taken as a last minute concern.

2.3 COMMENTS REGARDING TESTING

SAI has examined production testing as it relates to tactical electro-optic homing missiles and suggests that the optical transfer function and scattering measurement concepts are basically both sound and applicable. The U.S. Navy at China Lake, California, is active in investigation of scattering phenomena and measurement. Their activity is very thorough but perhaps too academic to have direct application to tactical homing missiles.

SAI is fast concluding that simple adaptation of the many scattering measurement options would be adequate for seeker and designator optics. A similar situation exists in optical transfer function measurement except for the fact that the techniques and explanations of OTF, derived from electrical engineering practices, are only a partial adaptation. This is to say that everyone seems to understand the "big picture," or idea of OTF at the component and assembly level, but few in the optics community are able to address its details on a practical level. Accordingly, SAI's work is concentrated on this

area. This concentration includes effort to interact with generally reluctant project offices (although the U.S. Army EQUATE office may be an achievable target), and to communicate their activities with the optical community at large. The optics community is making some progress toward adopting the pragmatism of Project Offices by organizing a group (which includes SAI) to arrive at specification via consensus standards.

Two categories of testing have been delineated by practical applications over the years. One category is particularly suited to in-process measurement while a single component is under fabrication. This category uses interferometric techniques to determine surface figure. However, once a component has been completed, it is best tested with regard to result system performance. This generally involves measurement of spectral efficiencies, scattering coefficients and spatial resolution.

Traditionally the spatial resolution was given in terms of limiting resolution. However, it was recognized that two systems could have the same limiting resolution yet have very different system performances. This results because limiting resolution implies specification of performance at a single spatial frequency. In practice, complex optical arrangements can include aperture shapes, obscurations and detection techniques that rely on spatial frequencies less than the limiting resolution. It is possible for an optical assembly with better limiting resolutions than another to actually give poorer system results if lower frequency components are important, as often is the case.

The most meaningful attempt to improve the appropriateness of component performance in an assembly grew out of linear systems theory and Fourier analyses. This is the approach most meaningful to evaluation of missile seeker optics. This approach is generally termed optical transfer function (OTF) analysis. It is discussed in the following sections and represents the SAI recommended approach for Phase II of this study.

3. OPTICAL TRANSFER FUNCTIONS

One of the better introductions to the theory and practice of optical transfer function measurements was published by Fred Abbot in the 1980 Optical Industry and System Purchasing Directory. This article is too lengthy for complete inclusion in this section. On the other hand, relegating it to an appendix status probably means it would not be read until after Sections 4 and 5, where the background information is actually needed. The compromise solution seems to be to abstract it in this section, with adherence to Abbot's overall text and organization. This abstraction follows:

3.1 HISTORY AND INTRODUCTION

Despite rapid grown in the field of optics during the late 1960s and the 1970s there is still a widespread acceptance of the criterion known as resolution. For many years the classical method of assessing image quality has depended upon the measurement of the limiting resolution of the particular system under evaluation or the system and film combination. This type of test can have the advantage of including the detector, as for instance in the photographic resolution testing of a lens to be used for photography, or the visual testing (by observing adjacent stars) of an astronomical telescope.

The tests are tedious to perform and must be carefully controlled to be meaningful. Furthermore, the information that they provide is of little use for anything other than determining the limiting resolution of the system. Even so, the measurement must be extremely questionable, particularly when the image is received on a screen or viewed in a microscope. In these cases the resolution may be limited by the coarseness of the screen or the available magnification of the microscope.

The tests themselves produce results that are of little use to the optical designer as a quantitative guide to modifying his design. In addition, the type of test object, usually a three-bar square-wave target, bears little correlation to an actual scene since it is neither a typical shape nor comprises a single frequency.

Despite the problems associated with resolution, only a few of which have been listed above, it remains obstinately in use today as a basis for

manufacturing and evaluating optical systems. Only in the field of optical design has a more advanced terminology become universally accepted.

One of the biggest problems that has arisen in the last decade has been due to the introduction of a wide range of new electronic imaging systems, which has considerably magnified the problem of specifying and designing optical systems for use with them. It was determined many years ago, principally in the television field, that lenses with the highest resolution were not necessarily the best lenses for use with image orthicon tubes. As far back as 1948, an engineer by the name of Otto Schade, working at RCA, in a series of papers published in the Journal of the Society of Motion Picture and Television Engineers discovered the real key to specifying lenses and detectors in similar terms. Unfortunately, his papers went unnoticed for many years. The interested reader is strongly recommended to read these papers.

The establishment of a transfer function theory in optics, similar to frequency response in electrical circuits, provided the relationship that was required. For our purposes it is convenient to regard the transfer function merely as the relationship between the input and the output of an optical system. The theory utilized here was developed by many independent workers over the years and is based on a combination of electrical communication theory and optical diffraction theory. The foundations of the theory are based, to a large extent, on a book by P.M. Duffieux entitled, "L'Integrale de Fourier et ses Applications a L'Optique."

Unfortunately, this pioneering work was published privately in 1946 and is not generally available. Many developments of Duffieux's theory did take place, however, at Imperial College, London between 1952 and 1960. The result of this work, which was under the direction of H. H. Hopkins was published mainly in the Proceedings of the Physical Society and the Proceedings of the Royal Society.

Because of the versatility and completeness of Transfer Function Theory, it has become a standard practice today to specify and design systems in these terms. This has demanded an understanding of the principles from a wide variety of disciples - optical, mechanical, electronic and chemical engineers for example. It is the intent of this article, originally published as a four-

part series in Optical Spectra, commencing in March 1970, to provide for engineers a fundamental coverage of transfer function terminology.

The article will commence with an assertion of the basic principles and definitions and their application to optical systems. Calculations of diffraction-limited transfer functions will be explained, as well as computational techniques that have been widely utilized. Many measuring methods and their underlying theories will be described, and the article will conclude with a description of a particular instrument that was designed and built by the author. The instrument is modular in form and can be utilized in many different configurations, some of which will be described.

Basic Principles and Definitions

The quality of the image formed by an optical system is determined by three factors: 1. Aberration in the optical system; 2. The wave nature of light (causing diffraction effects); and 3. Inaccuracies incurred due to manufacturing processes.

When the design is such that the aberration can be neglected (as in the case of an f/2 lens stopped down to f/16) and errors of manufacturing are so small that they have no effect on the performance, then the quality of the image formed by the system is determined solely by the effects of diffraction and the system is said to be "diffraction-limited."

Consider, as an example, a lens systems that forms an image of an incoherently illuminated narrow slit. In the ideal case, the distribution of light in the image would be an exact replica of that in the object, demonstrated in Figure 3-1b. This can, of course, never be realized because of the finite wavelength of light, and the best that can generally be achieved is the familiar distribution of energy illustrated in Figure 3-1c.

If now there is aberration present in the optical system, and in particular if the aberration is asymmetrical (as, for example, in a lens afflicted with coma), then the image is extremely complex and could be of the form illustrated in Figure 3-1d. The intensity distribution in the image of a narrow incoherently illuminated slit is known as the "line spread function" of the optical system forming the image. If the slit is replaced by a pinhole the corresponding function is referred to as the "point spread function."

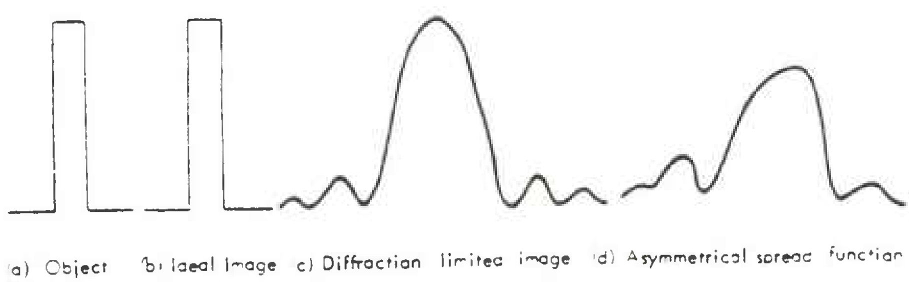

Figure 3.1

IMAGE OF A NARROW SLIT.

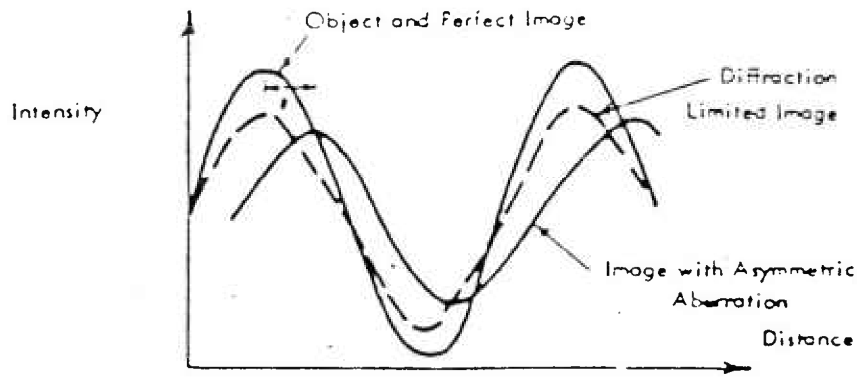

Figure 3.2

INTENSITY DISTRIBUTION IN THE IMAGE OF A SINE WAVE TEST OBJECT

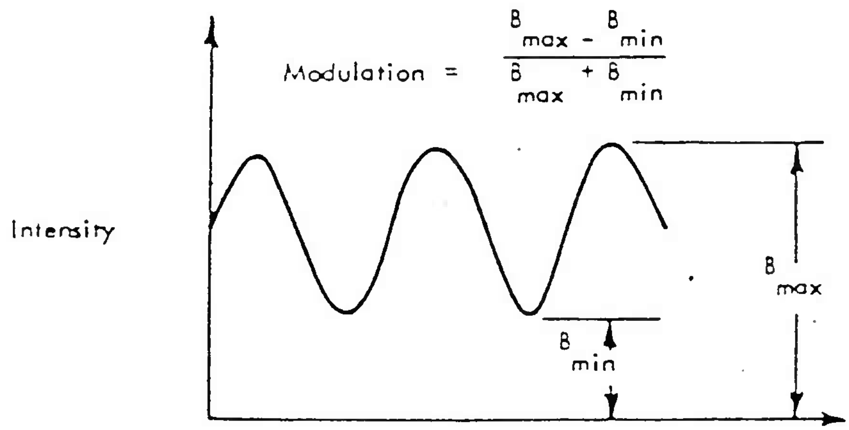

Figure 3.3

CONCEPT OF MODULATION

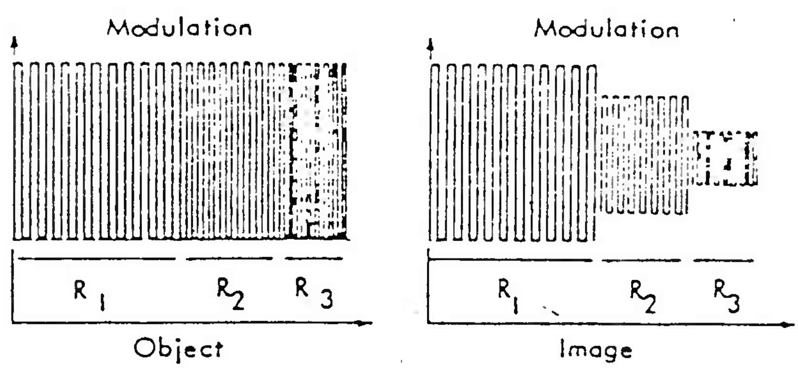

Figure 3.4

IMAGING SINE WAVES OF DIFFERENT FREQUENCIES

For the purpose of considering image formation, each point in the object can be thought of as a source, giving rise to a point spread function from different points in the object. This approach gives a good indication of the process of image formation, but is not, however, the best approach toward designing and assessing optical systems.

A more suitable test object can be obtained by utilizing a sinusoidal intensity distribution. For reasons to be discussed later, the image of a sinusoidal target always has a distribution that itself is sinusoidal. Behind this fact lies that whole basis for transfer function theory.

Consider a sinusoidal type target being used as a test object as illustrated in Figure 3-2. In the ideal case, the object and image are identical, but since this, in reality, is never the case, the best we can achieve would be a diffraction limited image. The effect of diffraction is to reduce the amplitude. If, in addition, aberration is present, the amplitude would be further reduced in the presence of asymmetrical aberration, the amplitude reduction is also accompanied by a phase change θ. If N is the distance between successive peaks of the target (in millimeters), the spatial frequency of the target is defined as $1/N = R$ cycles/mm. This is analogous to the familiar lines/mm term used for resolution charts. In the case of afocal systems, the units more frequently used are cycles/milliradian.

An important property of the sinusoidal intensity distribution that we will utilize is the modulation as defined in Figure 3-3. It will be noted that the mean luminance is taken high enough to bias the function such that the luminance is always positive. The modulation defined in Figure 3-3 is often referred to as the contrast, but since the definition of contrast is not always the same, particularly in the photographic field, the term modulation will be adhered to.

If we next consider a series of sinusoidal targets of varying spatial frequency, but of constant amplitude, as subsequent test objects (shown in Figure 3-4) their images will be of reduced amplitude and the corresponding modulation can be calculated for each spatial frequency. If we define the modulation at zero cycles to be 1.0, a graph can be plotted of modulation against spatial frequency (Figure 3-5). This represents the variation of modulation with spatial frequency and displays when is common known as "Modulation Transfer Function" curve, often referred to as an MTF curve.

In the case of a lens possessing asymmetrical aberration or badly centered elements, the effect of the lens system is to cause not only a reduction in modulation but, as previously mentioned, this will be accompanied by a phase change. This phase change is dependent upon spatial frequency and contributes to what is known as the "Phase Transfer Function (PTF)." It is conveniently represented by the type of graph shown in Figure 3-6. Particularly note that this is a spatial phase shift and can only occur where the point image is asymmetric. Thus, in a centered optical system, spatial phase shifts occur only "off-axis" and for tangentially oriented lines. Radial lines will have no phase shift.

An interesting effect can be observed when defocusing a symmetrical lens, when phase shifts of 180° can occur. This is consistent with visual observations when compared with the more common experience of observing the alternate bright and dark centers to the on-axis diffraction pattern as the system is traversed through focus.

Measurements of Modulation Transfer Function and the Phase Transfer Function combine to give what is known as the "Optical Transfer Function (OTF)" for the system under test.

It might not be out of place at this point to discuss the various terms that have been used in recent years. The International Commission for Optics, at a meeting in London in July, 1961, considered the alternate terms used to express the Optical and Modulation Transfer Functions (among these we can include sine-wave response, frequency response, contrast transfer). It was decided in the interest of standardization that the terms to be recommended for universal use would be the ones defined above, namely Optical, Modulation, and Phase Transfer Functions.

The use of one Optical Transfer Function is insufficient to specify an optical system since the OTF varies considerably for any one system and depends on the following seven parameters: 1. Aperture; 2. Field angle; 3. Inclination of test target; 4. Focal setting; 5. Object distance; 6. Color balance of illuminant; and 7. Orientation of lens mount. All of the above must be known and stated before a particular curve can be reproduced.

To summarize, the image quality of an optical system can be specified completely and objectively by means of its optical transfer function together

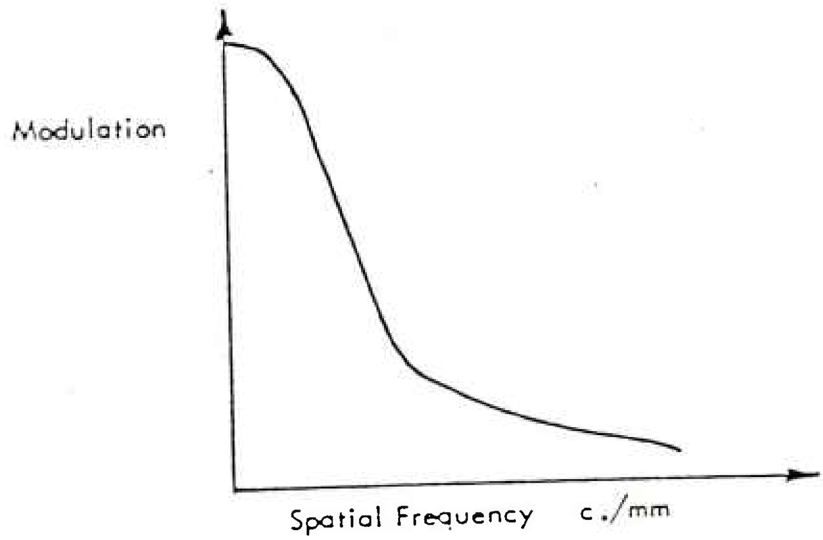

Figure 3.5
A TYPICAL MTF CURVE

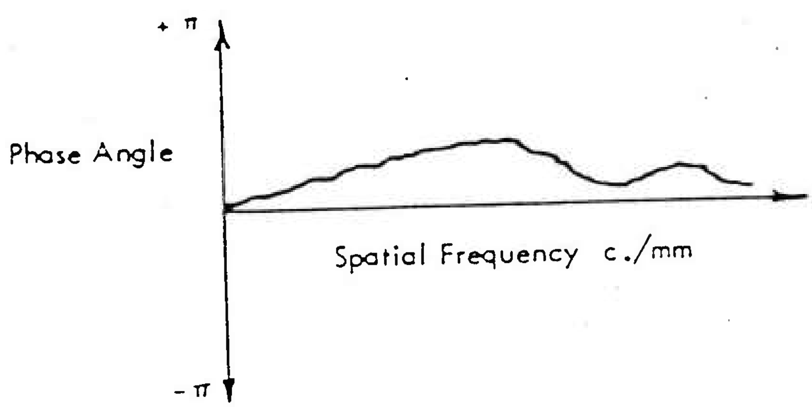

Figure 3.6
A TYPICAL PTF CURVE

with subsidiary information about veiling glare, distortion, field brightness, etc.

Application of Transfer Function Theory

Armed with a knowledge and understanding of transfer functions, we can now proceed to discuss some of their applications to optical systems. Probably one of the greatest advantages to be gained by using transfer functions is that of cascading system elements. This cascading property permits the lens transfer function to be combined with that of the detector.

For example, consider a camera lens with an MTF of 0.5 at 20 c/mm being used with a film whose MTF is 0.7 at 20c/mm. The combination will have a modulation of 0.35 at 20c/mm. If the object that the camera photographs has a modulation of 0.1, then the cascading process is further applied to give an overall modulation of 0.035.

Despite the elegance of this approach, there is one very serious drawback. If two lenses are used in tandem, the transfer functions of the lenses cannot be cascaded to give an overall transfer function unless a ground glass screen is interposed between the two lenses.

This fact should be obvious when we consider that the overall correction of a lens system is usually infinitely better than any of its elements. If, for example, the MTFs of the inidividual elements were cascaded, the overall MTF of the system would be considerably worse than the MTF of any of its components. This is a consequence of the fact that aberration introduced by one element can compensate for that introduced by another element in the same system.

A good illustration of the above discussion can be obtained by considering the situation that we previously discussed involving the television industry. If reference is made to Figure 3-7, it will be noticed that the two lenses, A and B, have different MTFs but equivalent cut-off frequencies. Resolution tests would show the two lenses to be equal, although they would perform differently under different conditions of use. If, for example, the image detector has a low cut-off frequency (as with most electronic tubes), then lens B would be suitable. If, on the other hand, a detector with a higher

frequency were used (a reconnaissance film, for example), then lens A would be the superior lens.

The general aim should be to design a lens to match the detector response. While this approach was not available some years ago, it is now possible to accomplish this confidently. A typical problem encountered is illustrated in Figure 3-8, in which the MTF curve is shown for an f/1.3 system to be used for a low-light-level application. The low "f" number is required because of the small amount of light available. Suppose now that the lens is to be used with an image tube that has a cut-off at 40c/mm. The natural tendency of the lens is to maintain a steady reduction in response, out to the cut-off frequency (1450c/mm). Such a lens would not be suitable for operation in the 0 to 40c/mm range. The problem then, is one of maintaining a high aperture and optimizing the response at the lower frequencies at the expense of lower response at frequencies beyond the cut-off of the tube.

The use of transfer functions in optical design has become almost universal and this, with measurement of the manufactured product, has provided the optical designer with a very elegant tool. It is standard practice to submit a final optical design to MTF calculations to enable the designer to compare his design with that of the lens and made subsequent adjustments in the design, if required. A point of further interest at this stage is that possible over-designing of the system can be observed and compensation made.

When the final manufacturing process is complete and the lens parameters have all been measured, the lens system can be subjected to MTF tests. The results can be compared directly with the optical design by reinserting all the known manufactured data into the computer program and calculating appropriate transfer functions. Adjustments can then be made in the final product until satisfactory results are obtained.

The Theory of Measuring Techniques

Many methods have been developed over the past decade to successfully measure the modulation transfer function of an optical system. Some methods, the direct ones, utilize a sinusoidal scanning screen; others can be used to measure the MTF indirectly by measuring, for example, the line spread function and subsequently calculating the optical or modulation transfer function from the

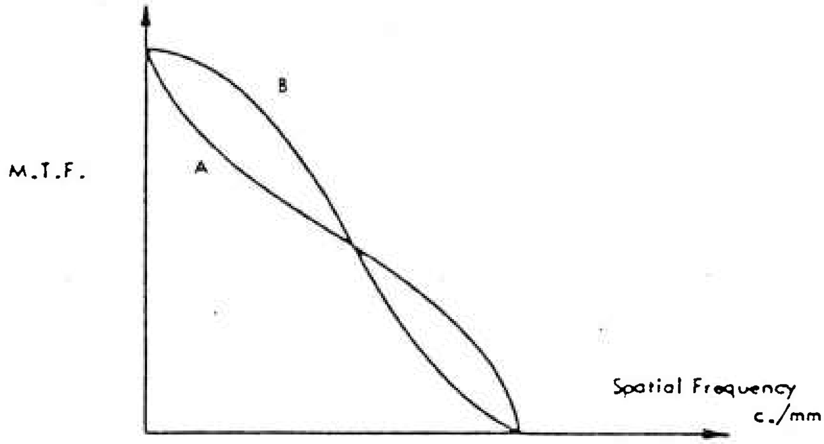

Figure 3.7

A COMPARISON OF EQUI-RESOLUTION LENSES

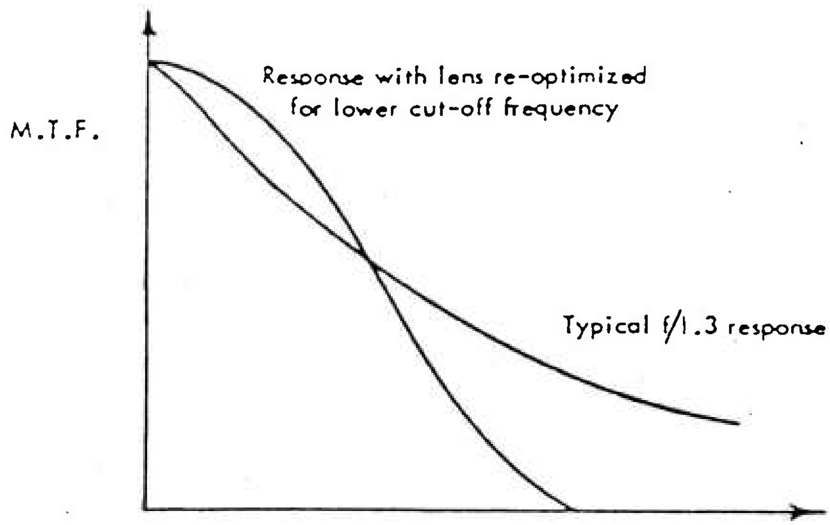

Figure 3.8

MTF OF F/1.3 SYSTEM FOR LOW-LIGHT-LEVEL APPLICATION

measured data using a high-speed digital computer. The type of method utilized is somewhat dependent upon the reason for testing. If, for example, the test is to be considered as a quality control tool on a large batch production type lens, then it is probably not necessary to measure the actual MTF, but instead to assess some related quantity that can be assigned a number signifying either the acceptance or rejection of the lens under a particular set of circumstances.

In principle the method of measurement is simple when we consider that the elementary theory calls out the response of the system to a suitable range of spatial frequencies. For example, a sine-wave target of fixed spatial frequency may be used as a test object. The image is itself sinusoidal and, in the image plane, a narrow slit is placed perpendicular to the direction of modulation of the sine-wave target. A phototube is used to measure the light transmitted through the slit as the sine wave is translated across the object plant. This yields the modulation at a single spatial frequency.

To obtain the complete MTF curve, targets of various spatial frequencies, together with a target for defining the modulation at 0c/mm are required. It will be recognized that each component in the system will have, itself, a transfer function and in this respect, the effect of both the various types of targets on the finite width of the slit must be considered.

Broadly speaking, the measuring techniques can be broken down into two distinct categories; those involving scanning devices and the infinitely slower interferometric type measurements. A classification will be given of the various techniques and the basic theory underlying the techniques, involving the use of several forms of scanning screens.

Classification of Methods

It is convenient to divide the various methods into two types: scanning and interferometric. Each section will be broken down further according to the method used for scanning and the type of target present.

A. Scanning Techniques
   1. Direct Method
      a. Sinusoidal Screen
      b. Sine-Cosine Pairs Type Screen

c. Square-Wave Screen

d. Moire' Fringe Type Screen

2. Indirect Method

a. Line Spread Function Analysis

b. Edge Trace Analysis

B. Interferometric Techniques

1. Autocorrelation Methods

2. Cross Correlation Methods

Types of Grating

By far the most critical component in the measuring system is the target, and it is not difficult to obtain an MTF if a good sinusoidal grating is available. Recognizing the difficulty of producing accurate sine-wave targets, many workers have resorted to other forms of targets such as square wave and Moire'-fringe types. In order to classify the types of targets, the following distinctions are made:

1. Density Type Target
   a. Spatial Frequency is changed step by step
   b. Spatial Frequency is varied continuously in time
2. Area Type Targets
   a. Spatial Frequency is changed step by step
   b. Spatial Frequency is varied continuously in space

Area Type Targets

It is more frequently convenient to utilize a grating of the area type instead of the one of density type. To manufacture this, the original sinusoidal pattern is drawn and reproduced photographically on high-contrast film by a distortionless lens. Since high-contrast film is used, the loop characteristic has no effect on the waveform. A series of spatial frequencies can be included on a single film loop together with a normalization section (0 cycles/mm).

4. SAI APPROACH TO OTF

The OTF of a system can be obtained from the Fourier transform of the line spread function of the system under test. The following is an analog technique for determining the Fourier transform components directly from correlation of the line spread function with a sine wave. The system under test views a line source which is sinusoidaly modulated in intensity. The image plane is scanned to produce an electrical signal proportional to the product of the line spread function with a sine wave. This signal is then applied to an electrical integrator to obtain the value of the correlation integral for one frequency and phase. The process is repeated for three phases at each frequency for which the OTF is to be evaluated. The Fourier transform magnitude and phase at each frequency is calculated from these three measurements.

4.1 DEVELOPMENT OF OTF PROCESS

Figure 4-1 shows the basic process concept to be analyzed. This includes a source function represented by a modulated sine wave, a system response resulting from the transfer characteristics of the test system, and an observation plane in which an output distribution function is to be constructed.

The light intensity at a position along the line spread is given by

$$I_2(X) = G_1 L(X) \left[I_s \sin(\omega t+\phi) + I_o\right] \tag{4.1}$$

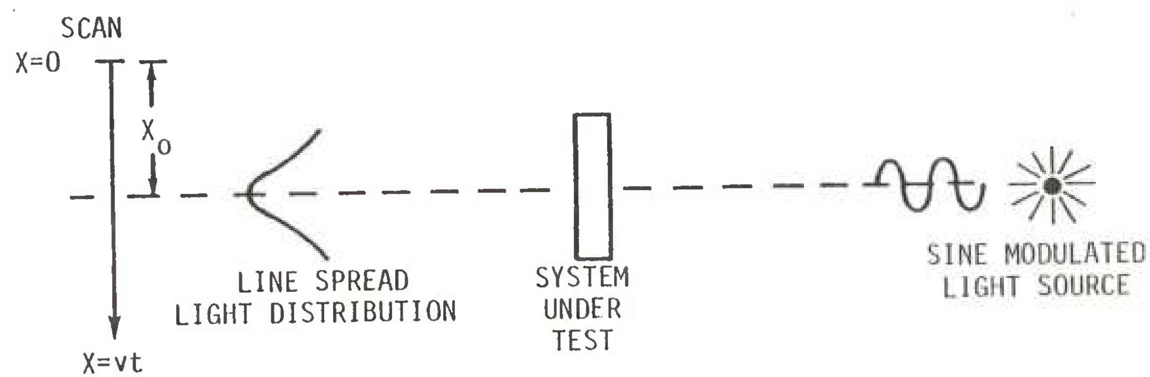

Figure 4.1 OTF Measurement Concept

where

$L(X)$ is the line spread function

$I_2(X)$ is the intensity along the line spread function

G_1 is the loss through the system

I_o is the DC component of the light source

I_s is the sinusoidal component of the light source

The scanning system will produce an output

$$e(t) = G_2 I_2(vt) \text{ where} \tag{4.2}$$

$e(t)$ is the electrical output of the detector system

G_2 is the gain of the detector system

v is the velocity of scan

thus

$$\begin{aligned} e(t) &= G_1 G_2 L(vt) \left[I_s \sin(\omega t + \phi) + I_o \right] \\ &= f_L(t) \left[\sin(\omega t + \phi) + B \right] \end{aligned} \tag{4.3}$$

where

$$f_L(t) = G_1 G_2 L(vt)\, I_s$$

$$B = I_o / I_s$$

$e(t)$ is applied to an electrical integrator which performs the operation

$$g(\omega,\phi) = \int_0^\infty e(t)dt = \int_0^\infty f_L(t) \left[\sin(\omega t + \phi) + B \right] dt \tag{4.4}$$

This may be written as

$$g(\omega,\phi) = \int_0^\infty f_L(t) \sin(\omega t + \phi)\, dt + C$$

where

$$C = \int_0^\infty B f_L(t) dt \tag{4.5}$$

Notice that $g(\omega,\phi)$ is the correlation function of the line spread with a sine wave. Since $g(\omega,\phi)$ will also be sinusoidal, it can be completely described in terms of samples taken at three phases. These samples are defined as

$$\begin{aligned} f_1 &= g(\omega, \phi_o) \\ f_2 &= g(\omega, \phi_o + \tfrac{\pi}{2}) \\ f_3 &= g(\omega, \phi_o + \pi) \end{aligned}$$

Evaluating equation 1 for the three phases yields

$$f_1 = \int_0^\infty f_L(t) \sin(\omega t + \phi_o)\, dt + C \tag{4.6a}$$

$$f_2 = \int_0^\infty f_L(t) \cos(\omega t + \phi_o)\, dt + C \tag{4.6b}$$

$$f_3 = \int_0^\infty f_L(t) \sin(\omega t + \phi_o)\, dt + C \tag{4.6c}$$

It can be seen that the first two samples are close to being the components of the Fourier transform and that the first and third sample can be averaged to determine the value of C.

The complex form of the Fourier transform is

$$F(\omega) = \int_{-\infty}^{\infty} f_L(t) e^{-j\omega t} dt \qquad (4.7)$$

If $f_L(t) = 0$ for $t < o$ then

$$F(\omega) = \int_{o}^{\infty} f_L(t)\, e^{-j\omega t} dt \qquad (4.8)$$

multipling $F(\omega)$ by a phase factor gives

$$F(\omega)\, e^{-j\phi_o} = \int_{o}^{\infty} f_L(t) e^{-j(\omega t + \phi_o)} dt \qquad (4.9)$$

which can be expanded to yield

$$F(\omega) e^{-j\phi_o} = \int_{o}^{\infty} f_L(t) \cos(\omega t + \phi_o)\, dt - j\int_{o}^{\infty} f_L(t) \sin(\omega t + \phi_o) dt \qquad (4.10)$$

Substituting equations 4.6 into equation 4.10 gives

$$F(\omega) = \left[(f_2 - C) - j(f_1 - C)\right] e^{j\phi_o} \text{ where } C = (f_1 + f_3)/2 \qquad (4.11)$$

or

$$F(\omega) = |F(\omega)| e^{j\theta} \qquad (4.12)$$

where

$$|F(\omega)| = \sqrt{(f_2 - C)^2 + (f_1 - C)^2} \qquad (4.13)$$

and

$$\theta = \phi_o - \tan^{-1} \frac{f_1 - C}{f_2 - C} \qquad (4.14)$$

Notice that in Figure 4.1 the peak of the line spread function occurs a distance X_o from the start of the scan so that the line spread function is shifted from the time origin by an amount of $T = X_o/v$.

Consider the shifted function

$$f_L'(t) = f_L(t + T)$$

then from equation 4.5

$$g'(\omega, \phi) = \int_{o}^{\infty} f_L'(t) \left[\sin(\omega t + \omega T + \phi) + B\right] dt \qquad (4.15)$$

It can be seen that the term ωT adds directly to the phase ϕ so that the

transform of a line spread centered at the origin can be obtained from the measured transform by subtracting ωT from the phase.

4.2 OTF PROCESS FOR FINITE SLIT WIDTH

In practice, the line spread function will be scanned with a slit. The transform of the slit must be used as a weighting function for the measured OTF as will now be shown.

$$h(\tau) = \int_{-\infty}^{\infty} f(x + \tau)\, \gamma(x)\, dx \text{ where } \tau = vt \text{ and} \tag{4.16}$$

$h(\tau)$ is the output from the slit

$\gamma(x)$ is the transmission function of the slit

$f(x)$ is the line spread function

v is the velocity of scan

The Fourier transform of $h(\tau)$ is given by

$$H(\omega) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x + \tau)\, \gamma(x)\, dx e^{-j\omega\tau} d\tau$$

$$= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x + \tau)\, \gamma(x)\, e^{-j\omega\tau} d\tau dx \tag{4.17}$$

substitute $\alpha = x + \tau$ then

$$H(\omega) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(\alpha)\gamma(x) e^{-j\omega(\alpha - x)}\, d\alpha dx$$

$$= \int_{-\infty}^{\infty} f(\alpha) e^{-j\omega\alpha} d\alpha \int_{-\infty}^{\infty} \gamma(x) e^{j\omega x} dx$$

$$= F(\omega) R(-\omega) \tag{4.18}$$

where

$F(\omega) = \int_{-\infty}^{\infty} f(\alpha) e^{-j\omega\alpha}\, d\alpha$ is the Fourier transform of the line spread

and

$R(\omega) = \int_{-\infty}^{\infty} \gamma(x) e^{-j\omega x}\, dx$ is the Fourier transform of $\gamma(x)$

The Fourier transform of a rectangular slit is now given. The transmission function of the slit is defined as:

$$\gamma(x) = 1; \; -\frac{a}{2} \leq t \leq \frac{a}{2} \qquad \text{where a is the slit width} \tag{4.19}$$
$$= 0 \text{ elsewhere}$$

Then

$$R(\omega) = \int_{-\infty}^{\infty} \gamma(x) e^{-j\omega x} dx = \int_{-\frac{a}{2}}^{\frac{a}{2}} e^{-j\omega x} dx = \left.\frac{-e^{-j\omega x}}{j\omega}\right|_{-\frac{a}{2}}^{\frac{a}{2}} \tag{4.20}$$

$$a \frac{e^{j\omega\frac{a}{2}} - e^{-j\omega\frac{a}{2}}}{2j\frac{\omega a}{2}} = a\left(\frac{\sin\frac{\omega a}{2}}{\frac{\omega a}{2}}\right) \tag{4.21}$$

The measured OTF will also be weighted by the Fourier transform of the source slit. According to linear system theory, $F_0(\omega) = OTF(\omega)F_{IN}(\omega)$ where

$F_{IN}(\omega)$ is the Fourier transform of the source distribution

$Fo(\omega)$ is the Fourier transform of the image distriubtion

$OTF(\omega)$ is the OTF of the system under test

4.3 DYNAMIC RANGE ANALYSIS

The following is a worst case analysis of the dynamic range of the OTF measurement system. First consider the width of the slit which scans the line spread function. Since the light received by the detector is proportional to the slit width, it is desirable to make the slit as wide as possible to increase the signal level. Since the measured OTF will be weighted by the Fourier transform of the slit, a wide slit will give greater attenuation of the higher spatial frequencies than a narrow slit. The slit width will be chosen to maximize the amplitude of the highest spatial frequency that the system is designed to measure. From equation 4.21 the slit transform is:

$$F(\omega) = a\,\frac{\sin(\frac{\omega a}{2})}{\frac{(\omega a)}{2}} = \frac{\sin\,(\frac{\omega a}{2})}{\frac{\omega}{2}} \tag{4.22}$$

For a given ω, $F(\omega)$ is maximum when $\frac{\omega a}{2} = \frac{\pi}{2}$

or when $a = \frac{1}{2f}$.

If the higher spatial freuqency is 100 cycles per mm, then $a = 5\ \mu m$. The weighting factor due to this width detector slit is:

$$K_1 = \frac{\sin\frac{\pi}{2}}{\frac{\pi}{2}} = \frac{2}{\pi} = 0.637$$

The source slit should be chosen to be M times the width of the detector slit where M is the ratio of the collimator focal length to the focal

length of the system under test. Under this condition, the apparent size of the source slit will equal the detector slit. The overall weighting of the OTF due to both source and detector slits will then be

$$K_T = K_1 K_2 = (0.637)^2 = 0.405$$

The power available from the collimator is considered next. A black body source with the following characteristics is used.

Temperature: 1250° K

Aperture: 355 μm diameter

The power density integrated over the spectrum

$$W_T = 5.67 \times 10^{-12}\ T^4 \text{ watts}$$

at 1250°K

$$W_T = (5.67 \times 10^{-12})\ (1.25)^4\ 10^{12} = 13.8\ \frac{W}{CM^2}$$

The spectral distribution curve for 1250°K indicates that 38% of this power will be in a 1 μm wide range centered about 3 μm.

The power emitted from the source slit is then given by:

$$P = 0.38\ W_T aD$$

where a is the width of the slit

and D is the diameter of the source

For the 25 μm slit and 355 μm diameter source

$$P = 0.38\ (13.8\ \frac{W}{CM^2})\ (0.025\text{ mm})\ (0.355\text{mm})\ (10^{-2}\ \frac{CM^2}{MM^2})$$

$$= 0.0465 \times 10^{-2} W = 0.465 \text{ mW}$$

The percentage of power radiated by the slit that is intercepted by the collimator will now be computed. Assuming an F3 collimator is used, the angle from the focal point to the edge of the collimator is

$$\theta_1 = \tan^{-1}\ (\tfrac{1}{6}) = 9.5^\circ$$

The divergence of the power radiating from the slit is determined by Fraunhofer diffraction. Each frequency of the Fourier transform is related to a diffraction direction according to the equation

$$\omega = 2\pi \sin \theta/\lambda$$

where ω is the radian spatial frequency

θ is the angle of wave from the optical axis

λ is the wave length of the radiation

The Fourier transform of a slit is given by equation 4.21. The power radiated from the slit is proportional to the square of the transform. Thus, the amount of power intercepted by the collimator is obtained by integrating the transform square over the band of spatial frquencies from zero to that corresponding to the angle θ . In equation (4.21), let $x = \frac{\omega a}{2} = (\frac{a \sin \theta}{\lambda}) \pi$. Then for the angle θ_1 and a wavelength of 3 μm

$$x = \frac{(0.025)(0.165)}{(0.003)} (3.14) = 4.32$$

The percentage of the total power radiated from the slit that is intercepted by the collimator will be given by

$$\beta_1 = \left[\int_0^{4.32} \frac{\sin^2 x}{x^2} \right] \Big/ \left[\int_0^{\infty} \frac{\sin^2 x}{x^2} \right] (100\%)$$

$$\beta_1 = 95\%$$

The power collimated onto the system under test will then be

$$P_2 = \beta_1 P = 0.95\ (0.465\ \text{mW}) = 0.442\ \text{mW}$$

Temporarily assuming no loss in the system, this power will be spread over the line spread function. Assume a worst case spread of 1 mm, then since the detector slit is 0.005 mm, the power received by the detector will be 1/200 of P_2.

$$P_D = P_2/200 = 0.442/200 = 0.00221\ \text{mW}$$

$$PD = 2.21\ \mu\text{W}$$

The detector has a minimum detectable signal of 1 nW so the dynamic range for measurement of low spatial frequencies will be 2210 to 1. The OTF weighting factor at 100 cycles per millimeter is $K_T = 0.405$ so the dynamic range for measurement at 100 cycles will be

$$D.R. = (0.405)(2210) = 895$$

The dynamic range for any system having significant light loss is given by D.R. times the fraction of light transmitted.

4.4 EXPERIMENTAL RESULTS

A lab setup which implements the preceeding technique has been devised. Figure 4-2 illustrates the apparatus used to demonstrate the concept. A microscope objective is used to focus the filament of the modulated bulb onto the source slit. A collimator is used to simulate a line source at infinity. The line spread function is scanned by a slit attached to a photodetector which is mounted on a translation table. The output of the photodetector is integrated electrically. The output of the integrator is measured with an A/D Converter and stored in the microprocessor memory. The microprocessor controls the rate of translation of the table and produces a square wave which is filtered to produce the sine wave modulation for the bulb. Three scans are made for each rate of the table. A different phase square wave is generated for each scan so as to obtain the three phase samples required for calculation of the OTF amplitude and phase. Ten rates are used ranging from 1 ms per step to 10 ms per step for the translator which advances 2.5 μm per step. The light frequency is 1.25 cycles per second. These parameters produce a range of spatial frequencies from 0.5 to 5 cycles per mm. The microprocessor outputs the magnitude squared and phase crossover curve to the XY plotter.

The lens tested is a biconvex simple lens with 135 mm focal length and F7 aperture. The result of testing this lens for focused and defocused condition is presented in Figures 4-3 and 4-4. Figure 4-3 is the focused case. Here the width of the line spread function was observed to be approximately 125 mm which should correspond to a first minimum of the OTF curve at 8 cycles per mm. Extrapolation of the OTF curve of Figure 4-3 produces a zero of 8 cycles per mm to a tolerance of less than ± 0.5 cycles per mm. Figure 4-4 is the defocused case. The first minimum of Figure 4-4 occurs at approximately 1.25 cycles per mm which corresponds to a line spread of 800 mm.

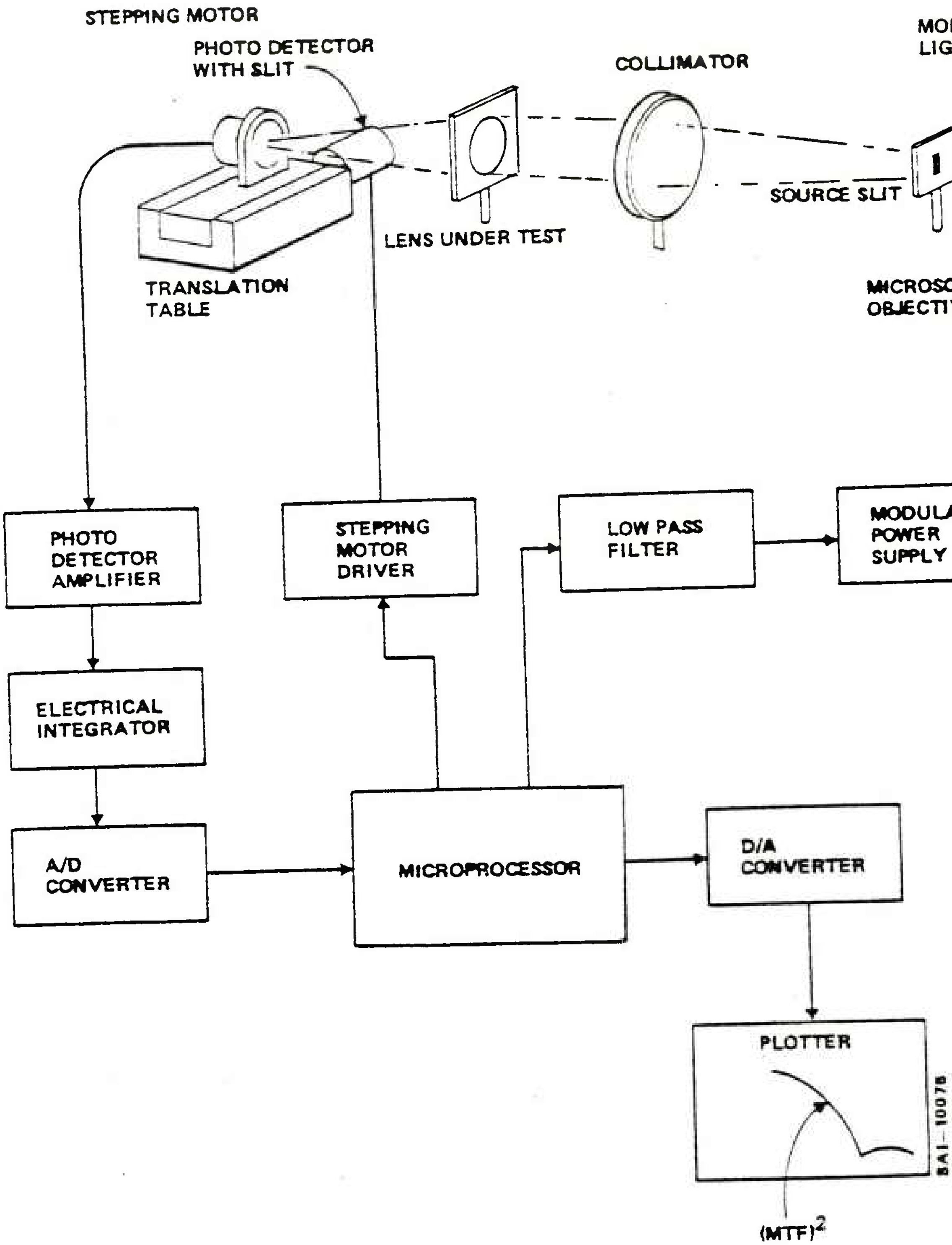

Figure 4.2 Demonstration of OTF Concept

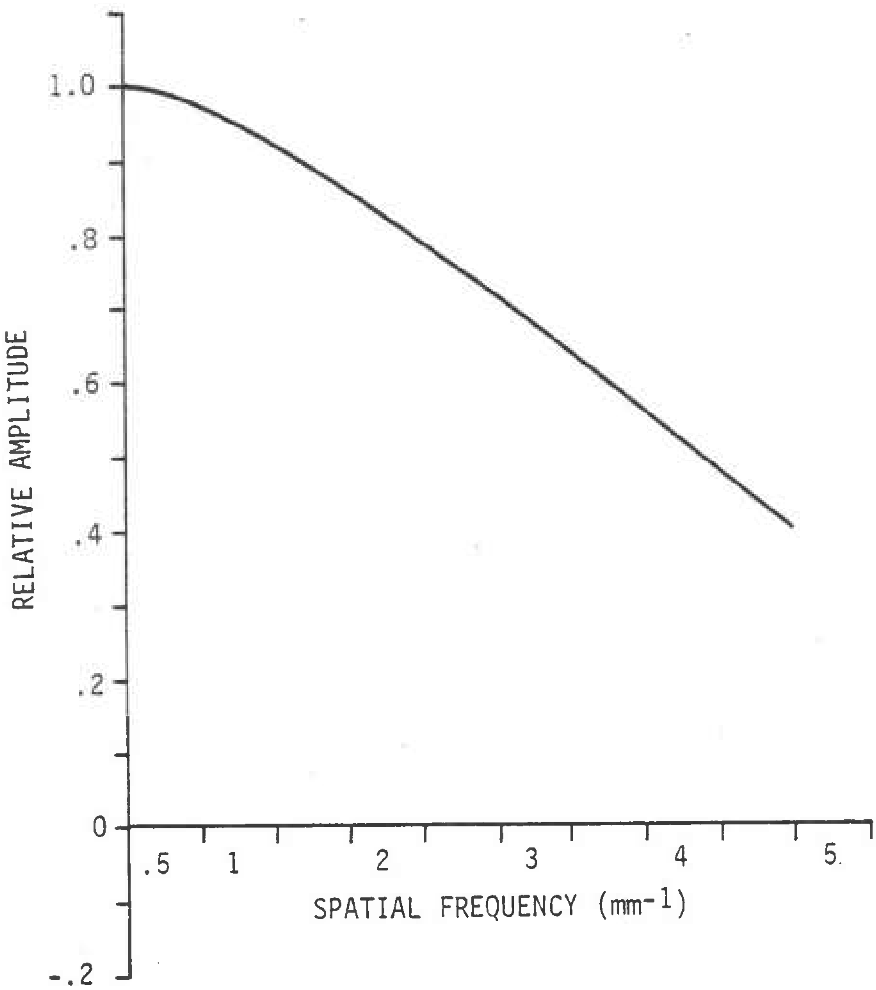

Figure 4.3 OTF of Biconvex Simple Lens (135mm F.L., F7) Focused Case

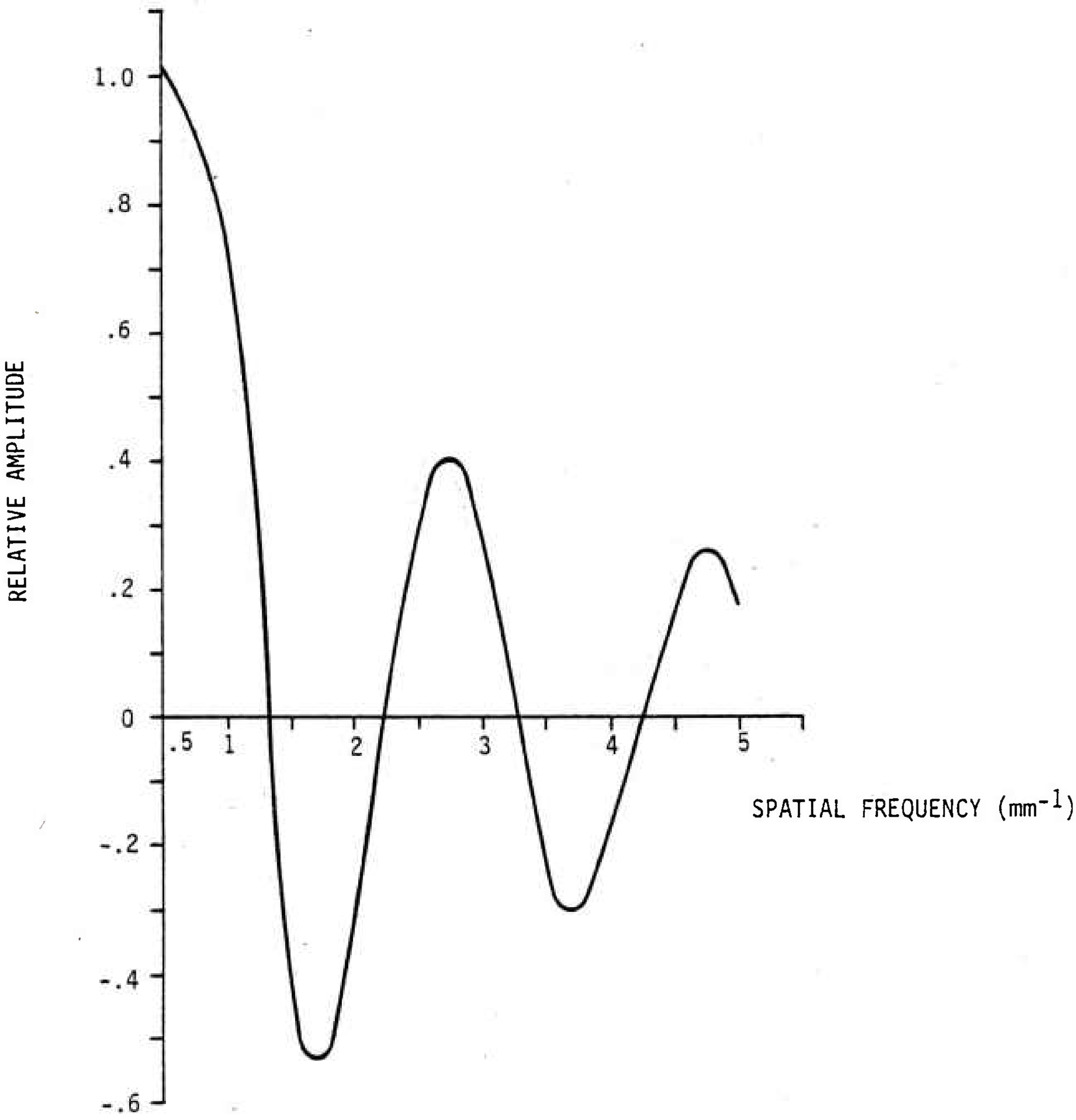

Figure 4.4 OTF of Biconvex Simple Lens (135mm (135mm F.L., F7) Defocused Case

5. RECOMMENDED MAINFRAME CONFIGURATION

The complete recommended mainframe assembly for the optical test facility is illustrated in Figure 5-1 including the control console. All optical and electronic support hardware directly related to processing and control are located on the optical mainframe. The controller terminal including the data acquisition system, data storage, CRT-keyboard assembly, and the line printer are remote from the optics mainframe. This division of the total assembly provides the user at the controller console with all necessary controls for system operation. All possible test functions are designed with automation in mind and, therefore, the need for operator access to the optics mainframe is minimized.

The principal difference between the mainframe indicated here and a standard optical table is its three dimensional nature. For all practical purposes, a table is only two dimensional and an optical bench is only one dimensional, (mirror adjustments excepted). Furthermore, standard tables and benches are not portable. The chosen mainframe is designed to be movable.

The mainframe concept is predicated on the recognition that repeated, detailed testing will be done on replicated components, assemblies and systems. All tests, however, require standard elements. These are generally thought of as standard sources and detectors. In addition, there is an implicit wavefront standardization. Optical engineers commonly utilize either or both of two standard wavefronts: the plane wave and the spherical wave. The mainframe incorporates a collimator for converitng a spherical wave into a plane.

In looking at the optics mainframe, a light path may be traced from the source assembly through a collimator. The path then proceeds from the second folding mirror through an aperture assembly to the test object. For the case of a transmission test system, the light path is traced to a detector assembly located behind the test system. If a reflection system is to be tested a beamsplitter directs the returned light onto a detector located to the side of the optical axis of the test system.

A refractive collimation system is indicated in the figure as a concept demonstration. However, the suggested design incorporates an off-axis parabolic reflector to provide greater flexibility in the choice of spectral range from 0.4 to about 10mm. More precisely, the reflectivity is relatively flat over this range and effects of chromatic aberations are eliminated.

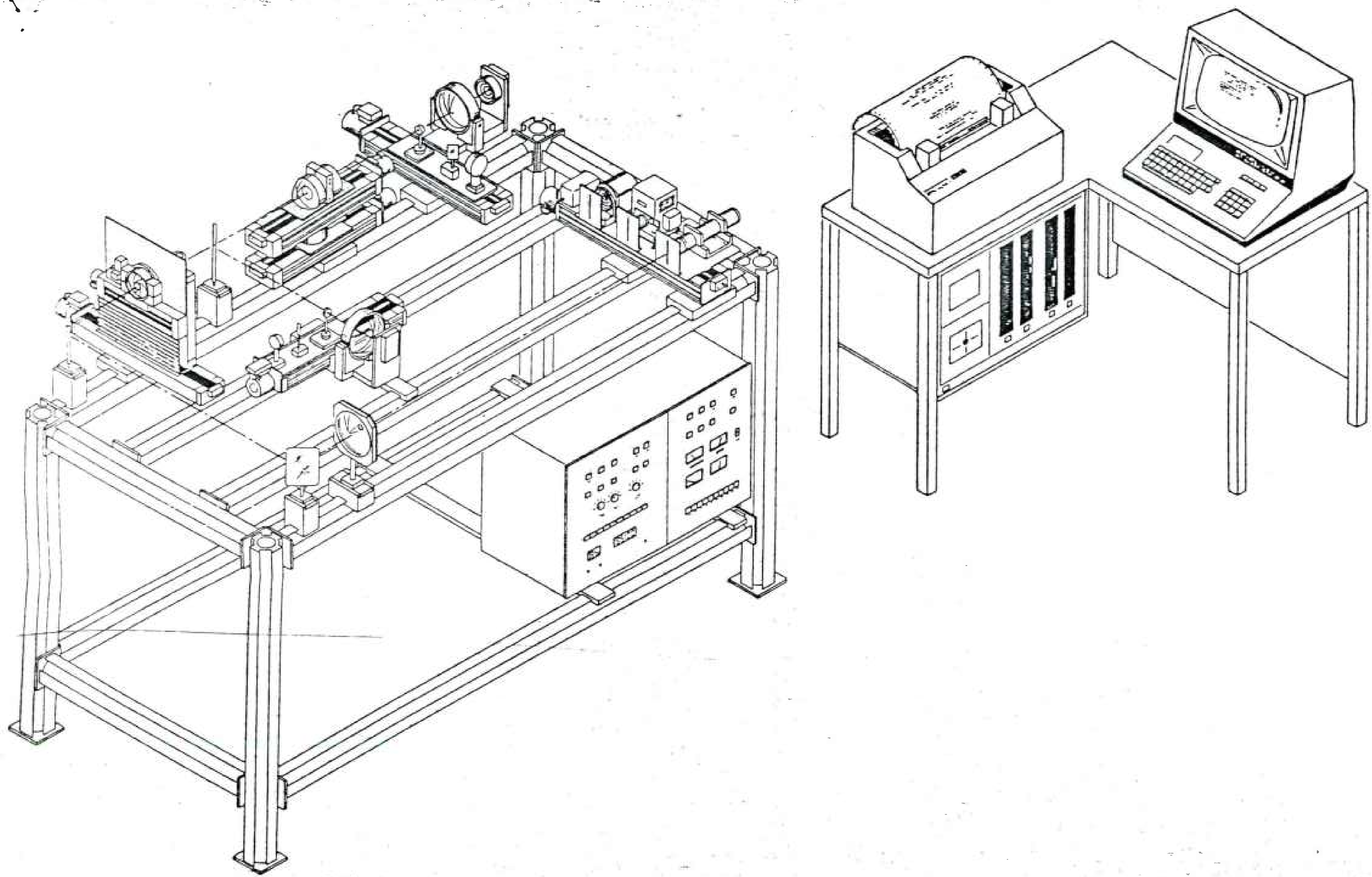

Figure 5.1 Mainframe Assembly for Optical Test Facility

5.1 MEASURED OPTICAL SYSTEM PARAMETERS

The test facility is designed to perform specific optical tests at the system or component level. The measured parameters include:

1. Focal Length
2. Optical Transfer Function
3. Large Area Scatter
4. Local Scatter
5. Spectral Characteristics

Depending upon the device being tested, a selection of tests is developed which adequately characterizes the system under its normal range of operating conditions.

5.1.1 FOCAL LENGTH

The test system is mounted on a universal test jig and aligned relative to a set of reference indicators. Figure 5-2 indicates the mechanical arrangement of the test assembly. A translator rotator combination is first used to locate the principle plane of the test object. The lower translator is positioned to focus a beam of light with the test object and then the rotator repeatedly scans the relative angular position of the optical axis. During this time, a detector is used to monitor the off-axis movement of the focussed beam. The upper translator adjusts the coincidence of the principle plane of the test object to the rotational axis by way of closed loop feedback with the off-axis detection. The lower translator is then again used to achieve focus of the beam and this determines focal length relative to the principle plane of the system. The advantages of this approach are:

1. Measured focal length relative to a true optical parameter (principle plane).
2. Convenient, practical implementation of a closed loop iteration procedure.
3. Ability to perform off-axis tests and evaluations of system performance with a single rotator.

5.1.2 Optical Transfer Functions

The Optical Transfer Function (OTF) of the test system or system components is measured using the same mounting arrangement following the focus

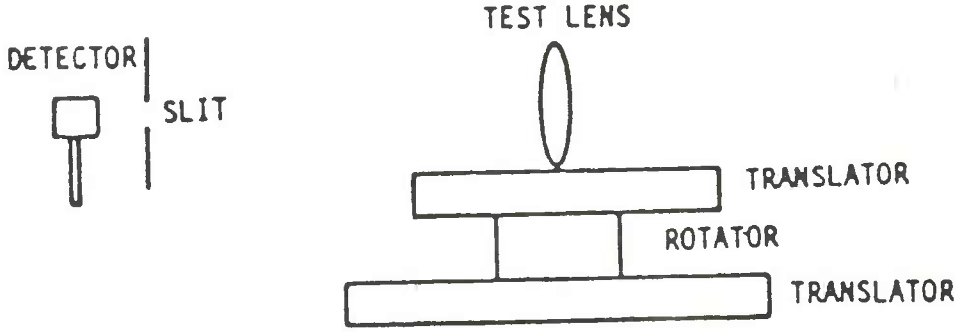

Figure 5.2 (a) Focus Measurement System

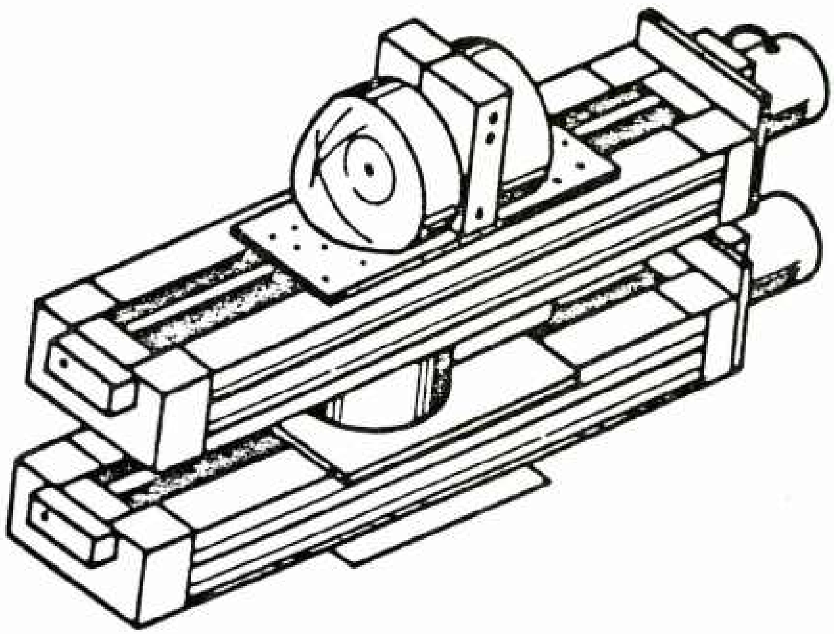

Figure 5.2 (b) Optical Support Assembly

measurement. The process concept is shown in Figure 5-3. The line spread function is obtained from a collimated source slit and modulated with a universal amplitude and a DC bias. The image of the line spread function is scanned across a sampling slit and detector. The output voltage response is then integrated to obtain the Fourier components as discussed in the previous section. The rotator located below the test object and aligned to the principle plane of the system can be used to position the test object for both on and off axis measurement of OTF while maintaining a reference for focal plane compensation.

All of the basic signal processing necessary to obtain Fourier component information is performed by the analog hardware before the data is transferred to the controller interface. This provides greater flexibility in sample frequency selection and in adaptability to specific system parameters.

The stepping accuracy of the slit scan necessary to achieve frequency resolution up to 100 lines/mm is about 1μm. In addition, slit widths on the order of 1 to 5 μm are also necessary. Therefore, in order to increase the operational speed, fast scans, high light levels and sensitive detectors are necessary. Rather than use a linear translator with a stepping motor drive, a rotating mirror galvometer scanner is used to scan the image of the slit across the detector as illustrated in Figure 5-4.

In the case of a test system or component which includes reflective optics, a beamsplitter is used to direct the reflected light onto the detector assembly. Figure 5-5 indicates the arrangement.

5.1.3 LARGE AREA SCATTER

Scatter measurements are performed in two steps. First, the total or large area scatter is determined by the detection assembly shown in Figure 5-6. A detector is used as a DC stop, collecting all light focussed by the test object. A large lens is used to collect the scattered light and focus it onto a second detector. The detector in the focal plane of the test system generates a feedback signal for normalizing the return signal representing scattered light.

5.1.4 LOCAL SCATTER

Local defects in the optical system being tested such as those characteristics conventionally classified as "scratch and dig" as well as

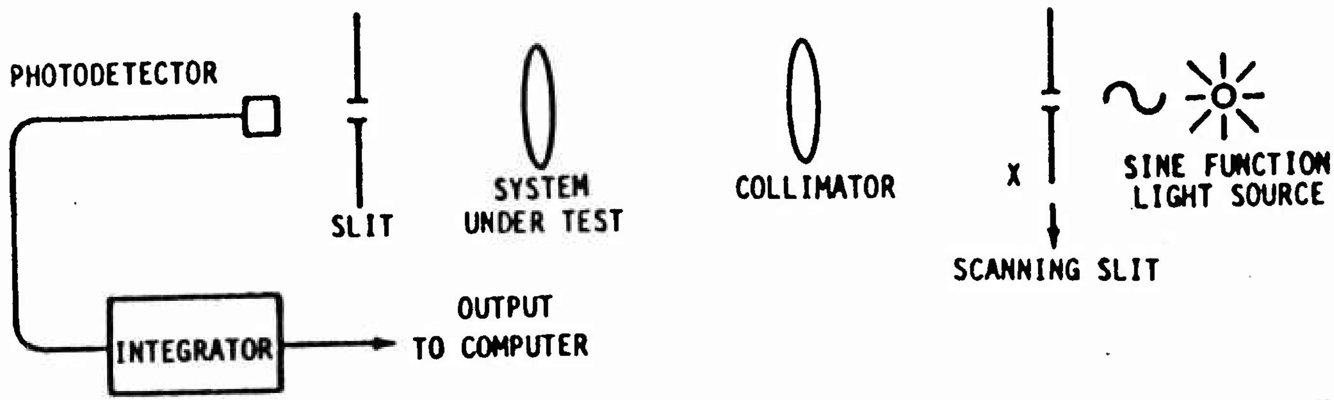

Figure 5.3 OTF Measurement System

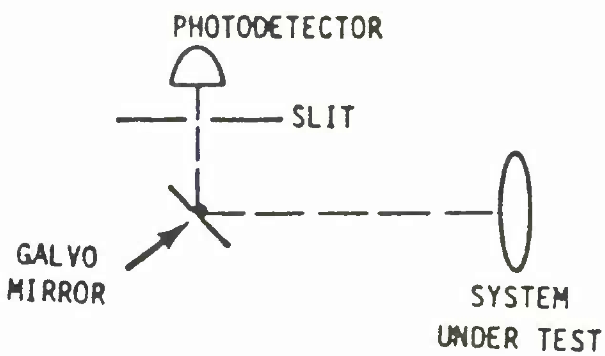

Figure 5.4 Rotational Scan OTF Detection

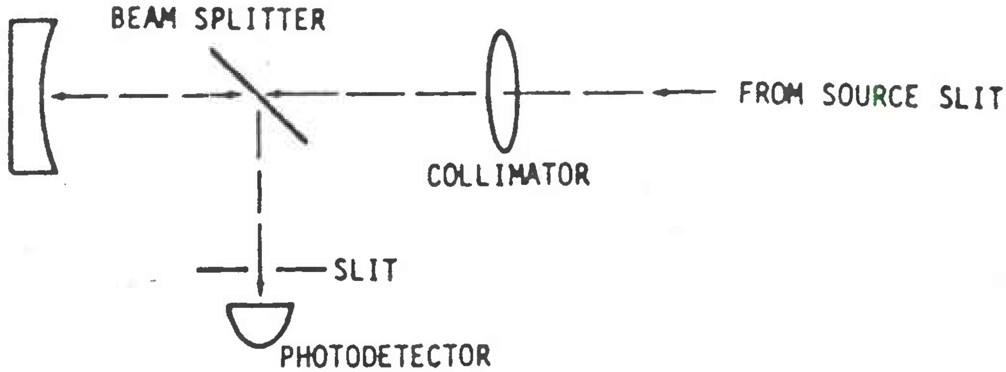

Figure 5.5 OTF Measurement of Reflection Optic

internal discontinuities will result in an increased contribution to the scattering. In order to identify the position and relative size of such defects, scattering measurements on a local level are made. These measurements are possible with the same detector assembly as used for total scattering.

A moveable iris diaphragm is positioned in a series of locations in the collimated beam which is input to the test object. The diameter of the iris opening is adjusted to test for a specific size or arrangement of defect. By scanning over the entire area of the input beam incident on the test system, a mapping of scattering centers can be made.

Additional detailed analysis is accomplished for specific areas as needed by altering the iris diameter or the path scanned. Figure 5-7 illustrates the test assembly for a particular sampling location.

The detector assembly used for all of the OTF and scatter tests is shown in Figure 5-8. The translation provides positional movement. As shown in the figure, the scattering detectors and collector lens are oriented in the optical axis. For OTF measurements, the galvonometer driven mirror is translated into position on the optical axis, thus deflecting the beam onto the detection-slit assembly located off-axis.

5.1.5 SPECTRAL CHARACTERISTICS

Two sources are provided to cover a wide spectral range from visible to infrared. A tungsten Halogen lamp is used to provide a high intensity source from 0.4 to about 2.5 μm. This source includes a monocrometer for obtaining narrow bandwidths in the range of 50 to 1000 nm. A black body source is provided to cover the spectral range in the IR from 1 to aobut 14 μm. Bandpass filters allow bandwidth selection over a range of 1 to 10 μm.

In addition, a laser source is available to aid in alignment and provide a single frequency coherent source. The laser is HeNe at a wavelength of 0.6328 um and with an output power of 1 mw or greater.

Coupled with each source is a focusing lens and a slit with a width of 10-100 m, which simulates a line source. All of the sources are mounted on a double translator arrangement as shown in Figure 5-19. A coarse translator provides source positioning in the optical path. A precision translator mounted

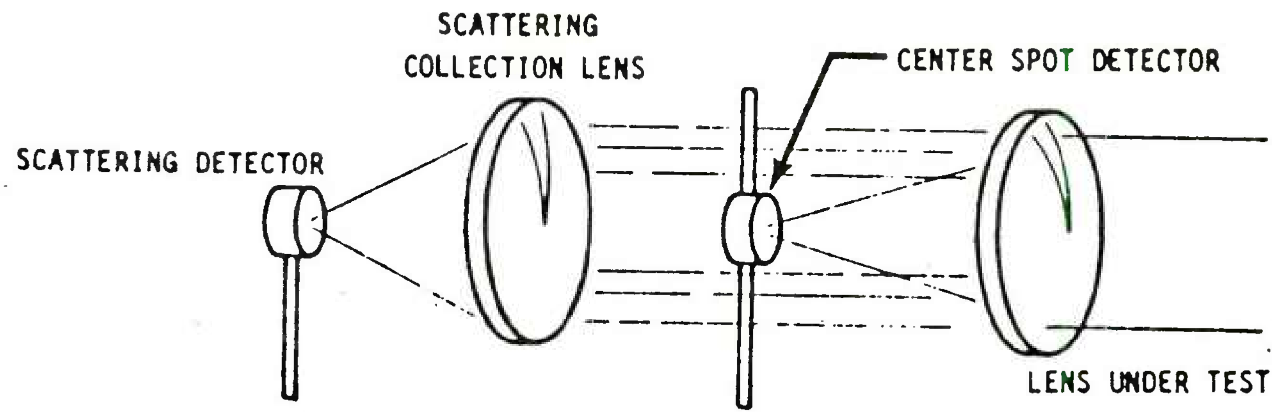

Figure 5.6 Large Area Scattering Measurement

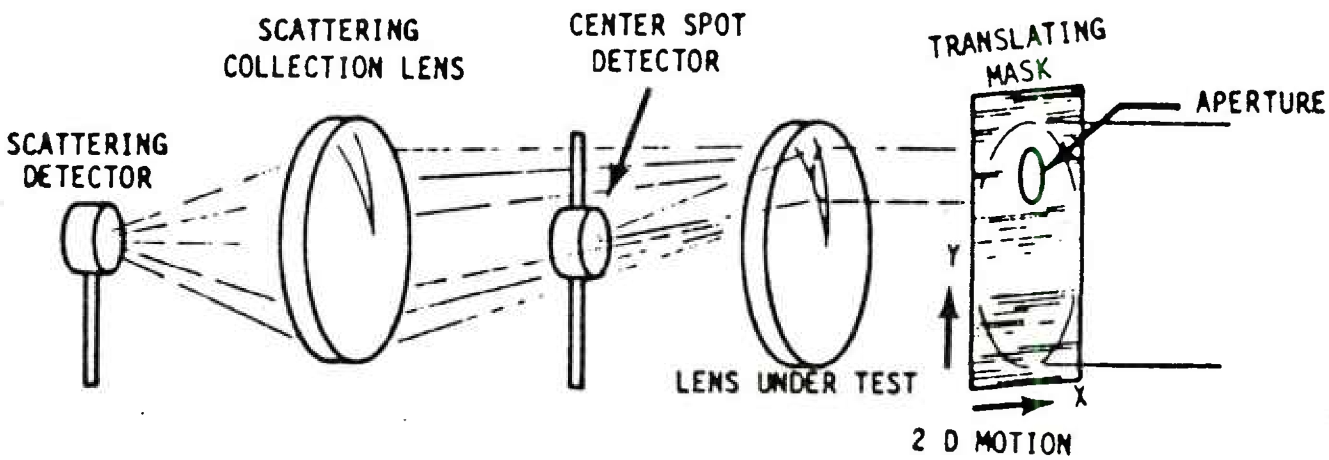

Figure 5.7 Local Scattering Measurement

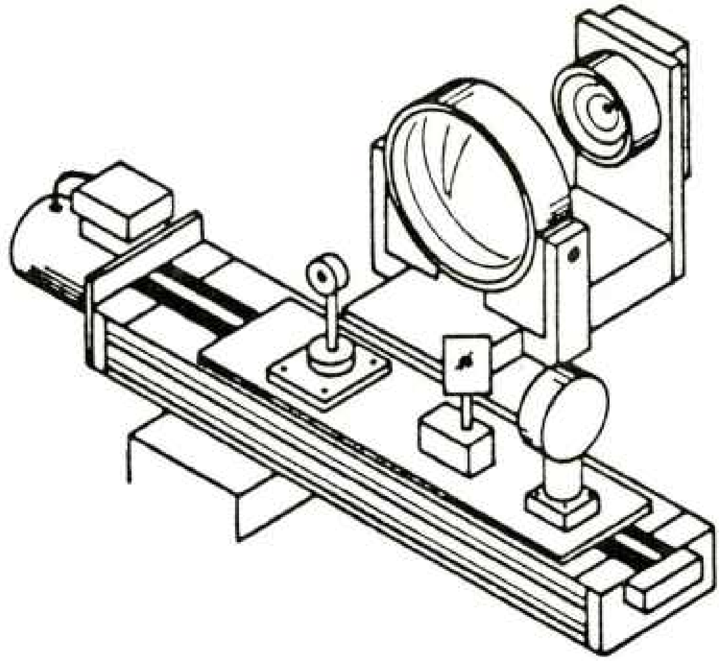

Figure 5.8 Detection Assembly

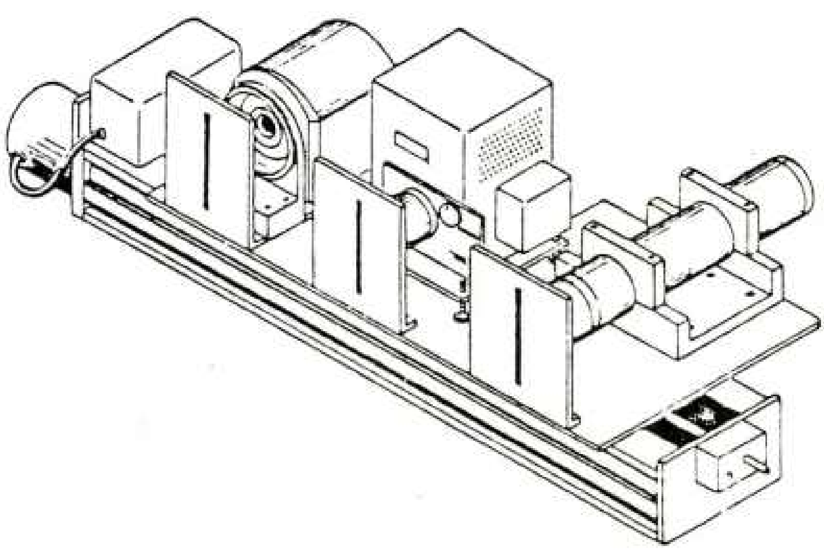

Figure 5.9 Light Source Assembly

between the coarse translator and the source plate assembly provides a source scan capability.

5.2 PROGRAMMABLE CONTROLLER

The programmable controller will be permanently connected by cable to the mainframe. The basic system will include a Cromemco Microprocessor Based System. The system will be capable of real-time branching based upon test results for a large array of tests. Input can be via keyboard and disk storage. Output can be by way of CRT display, printer and disk storage. The disk storage is 512K bytes. This allows large programs, result data keeping, statistics and inventory control.

The software for the pilot facility will be written using assembly language and FORTRAN programming. The devices chosen were selected based upon reasonable cost, ability to add features (peripherals, memory, etc.), ease of programming and low cost, reliable and convenient to use electronics interfaces (analog-to-digital converter packages, etc.).

The software chosen is designed in a highly modular fashion to enable easier development and maintenance. The basic modules are listed below and subsequently described in the remainder of this section.

- PRE-TEST SOFTWARE
  - Self-check & diagnostics
  - Source-to-detector alignment and calibration checks
- TEST SEQUENCE SOFTWARE
  - Component cataloging procedure
  - Servo positioning package
  - Analysis package
  - Statistics package

Pre-Test Software

Self-Checks and Diagnostics

A loop-back test will be developed to check and verify the electronics interfaces. It is suggested that these tests should be run after the system has been dormant for any prolonged period, test results begin to appear anomalous or the user desires to verify the overall condition of the system (e.g. after replacement of any electronic component).

Source-to-Detector Alignment & Calibration Checks

In routine daily operation, the second set of self-test programs should be run prior to each test configuration change. This series of tests is designated the "source-to-detector alignment and calibration checks" and is known by the shortened term "A&C checks." These checks are significantly more complex than the self-check and diagnostics, since the A&C checks establish for each source the path loss and detector sensitivity. The reading from each detector for a given test configuration optical path and source is identified and stored by the program for use by the analysis software during actual test execution.

Care must be taken to ensure that no source or ambient room light intensity changes occur inadvertently between the time that the A&C checks are run and the actual test sequence. To do so will likely affect the performance of the system.

The A&C checks will be sectored to enable only the sources and detectors needed to the particular test sequences to be run. A simple software matrix will be constructed to allow only testing of valid source-to-detector combinations. The calibrated value for each valid combination will be stored and used by the analysis package as the baseline value.

Test Sequence Software

Component Cataloging Procedure

One of the requirements of the system is to track the measurable parameters associated with each component being tested. Therefore, the serial number, part number and item description must be entered into the data base to enable this association and to perform statistical analysis of all components tested as required.

The component cataloging procedure also establishes a set of prerequisite conditions which call the proper process control tables which contain the test procedure and servo positioning command table identifiers. Thus, when the cataloging sequence is complete, the proper programs for the test to be run are loaded and are ready to execute.

Servo Positioning Package

This portion of the software contains a series of X, Y, Z and rotational commands which are required to position the various components in the optical path for testing. Normally the test sequences will call a particular positioning command or set of commands and enable the analysis package to "take a reading." After the measurement is made and recorded, the sequencer will step to the next positioning command set, take the next measurement, perform the next positioning commands, etc. until the sequence is complete. If the test sequence calls for use of multiple sources and/or detectors, the testing stops until the proper device is positioned and verified which requires the operator to acknowledge that the necessary manual actions are complete. The modularity of the software is such that discrete positioning commands can be changed without affecting the test sequence or any other software package.

Analysis Package

The test sequencer enables the analysis package to read the value from the active detector only after the servo positioning circuits have reached the quiescent state and the detector output is stable. The time delays induced before measurements are made is a function of detector characeristics inherent with each device and will be included as a clock driven table look-up value under software control.

The analysis package writes the digital equivalent of the analog detector output into the appropriate measurement parameter table for the component being tested. Further, it compares this measured value to the ideal value and produces a "figure of merit" interpretation of the results. Pass/fail criteria can be linked directly to thresholds stored in the program and recommended disposition of the component can be printed out.

Normally, even if a component fails a test step, the test sequence will be run to completion to fully evaluate all of the characteristics observable through testing. In this manner, a thorough analysis of the component can be obtained and the statistics package is able to receive all the required data for its historical file.

Statistics Package

A statistics package will be provided which will enable a profile of each type of component being tested. Types of data to be derived will include reason for failure, severity of anomaly, piece part and average quality values, disposition, recommendation for other uses, etc. It is anticipated that as the statistics base grows that the most common problems can be identified and rectified through improved manufacture, handling, packaging, or for whatever reason the problem exists.

5.3 PROGRAM SCHEDULE

Figure 5-10 shows a projected schedule for the continuation of the "Testing of Electro-Optical Components" effort. Highlights include an 8-month period for fabrication of the test device, plus an additional two months for system checkout and component testing. For this component testing and analysis activity, it would be necessary that MICOM provide SAI with a system to test.

Additional activity would include the definition of a full-scale test facility (leading to a written implementation plan), a demonstration of the test device to industry, motion-picture and still photograph documentation of the device, plus other appropriate reviews and reports.

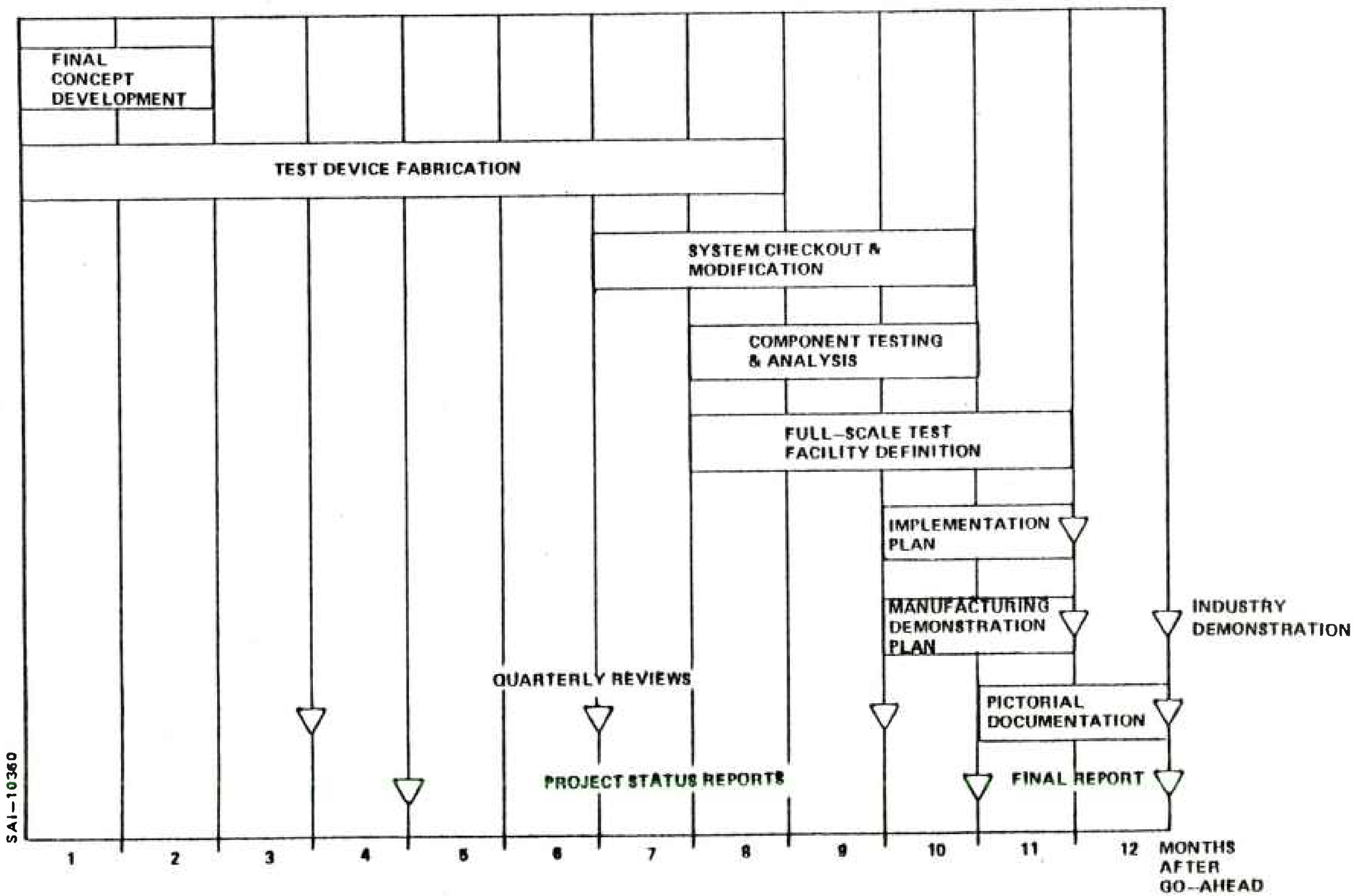

Figure 10. Program Schedule

APPENDIX A

HARDWARE PRICING

SUMMARY:

PARTS	$45,550.16
PROCESS CONTROLLER & PERIPHIRALS	11,599.00
MACHINE COSTS	5,350.00
	$62,499.16

ASSEMBLY A2 MAINFRAME

ITEM	VENDOR	MODEL	PG.	QUOTE	PRICE	QTY	PRICE	MACHINING	
2M Tubular Bench	ORIEL	1084	A24	CAT	289.00	4	1156		
1M Tubular Bench	ORIEL	1082	A24	CAT	148.00	2	296		
13M Tubular Bench	ORIEL	1080	A24	CAT	79.00	2	158		
Structural Members	Warrior-Hinkle			EST	900.00		900		
End Mount Plate	ORIEL	1071	A25	CAT	34.00	4	136.		
Connector Block	ORIEL	1070	A25	CAT	37.00	4	148.		
90^{O} Sliding Block	ORIEL	1074	A26	CAT	78.00	8	624		
Cross Member	Machine							$200.00	
							$3418.00	$200.00	SUBTOTALS

ASSEMBLY A2A1

ITEM	VENDOR	MODEL	PG.	QUOTE	PRICE	QTY	PRICE
Motor Controller 19"	ARDEL-KINEMATIC	C-100-D-2	7	CAT	2395	1	2395.00
Controller ACCESSY	" "	#24	29	CAT	18.00	1	18.00
Controller ACCESSY	" "	#26	29	CAT	29.00	1	29.00
Analog Controller	VELMEX	2A-7323-2	2	VERB	563.00	3	1689.00
Digital Controller	"	PIM-151		VERB	350.00	5	1750.00
Power Supply	Superior Elect.	MPS-3000			350.00	4	1400.00
Coordinate Translator	VELMEX	PIM-151		VERB	350.00	1	350.00
Power Supply 19"				EST		1	750.00
SIG AMP ASSY 19"				EST		1	1500.00
Control ASSY 19"				EST		1	750.00
UUT Control ASSY 19"				EST		1	500.00
TUNGSTEN Lamp P.S.	ORIEL	6329	D19	CAT	395.00	1	395.00
TEMP Controller	E.O.I.	1200	Data	CAT	575.00	1	575.00
Cabinet	Scientific Atlanta	E22 1920H		CAT	271.00	2	542.00
Misc/Electronics				EST			1000.00
							13643.00

ASSEMBLY A2A2 ILLUMINATOR ASSEMBLY

ITEM	VENDOR	MODEL	PG.	QUOTE	PRICE	QTY	PRICE	MACHINING
Helium-Neon Laser	Spectra Physics	147		List	675.00	1	$675.00	
V Block Laser Mount	ORIEL	661	B-4	CAT	110.00	1	110.00	
Optical Slit	ROLYN	70.1515	48	CAT	70.61	3	211.83	
Slit Mount	Machine				50.00	3		150.00
Diverging Lens	ORIEL	1596	B-4	CAT	76.25	1	76.25	
Focus Lens	ORIEL	1590	B-4	CAT	149.00	1	149.00	
Lens Mount	Machine							50.00
ASSY Bracket	Machine							50.00
Quartz Halogen Illum.	ORIEL	6130	D-16	CAT	522.00	1	522.00	
Quartz Halogen Lamp	ORIEL	6333	D-15	CAT	9.60	1	9.60	
Rear Reflector Assy.	ORIEL	6134	D-16	CAT	55.00	1	55.00	
Monochromater Filter	ORIEL	7155	E-5	CAT	425.00	1	425.00	
Focus Lens	ORIEL	7169	E-5	CAT	124.00	1	124.00	
Illum. Mount	Machine							100.00
Black Body Source	E.O.I.	W5123		CAT	1825.00	1	1825.00	
Black Body Mount	Machine							50.00
I.R. Focus Lens	EALING	22-5391	113	Verb	114.00	1	114.00	
Lens Mount	Machine							50.00
							$4296.68	$450.00

ASSEMBLY A2A2 ILLUMINATOR ASSEMBLY

ITEM	VENDOR	MODEL	PG.	QUOTE	PRICE	QTY	PRICE	MACHINING
Filter Wheel	ORIEL	2871	H2	CAT	375.00	1	375.00	
Wheel Mount	Machine							50.00
Motor Mount	Machine							150.00
ASSY Bracket	Machine							50.00
Source Mounting Plate	Machine							200.00
Plate Mount	Machine							50.00
Fine Scan Translator	ARDEL Kinematic	TO-100M	PG6	CAT	572.00	1	572.00	
Translator Mount	Machine							150.00
Rail Mount	ORIEL	1161	A22	CAT	155.00	2	310.00	
Filter Set	Corion			Verb	100.00	7	700.00	
Misc. Electronics				EST		1	750.00	
							$2707.00	$650.00

ASSEMBLY A3 & A4 DETECTOR ASSEMBLY

ITEM	VENDOR	MODEL	PG.	QUOTE	PRICE	QTY	PRICE	MACHINING
Pyroelectric Detector	ORIEL	7090-1	F-30	CAT	395.00	2	790.00	
Detector Housing	ORIEL	7093	F-30	CAT	165.00	2	330.00	
Longstem Housing	ORIEL	7094	F-30	CAT	220.00	1	220.00	
Pyroelectric Detector	ORIEL	7089-1	F-30	CAT	295.00	1	295.00	
Fused Silica Window	ORIEL	3810	F-30	CAT	24.00	3	72.00	
IRTRAN 2 Window	ORIEL	3814	F-30	CAT	55.00	3	165.00	
GALVO Scanner	Bulova	ALS-300	Data	Verb	345.00	1	345.00	
GALVO Mount	Machine					1		100.00
Collector Lens	EALING	22.5565	113	Verb	805.00	1	805.00	
Collector Lens Mount	Machine					1		100.00
Bracket Mount	Machine					1		200.00
Detector Locator Translator	Velmex	B4016P20J		Verb	572.00	1	572.00	
Translator Mount	Machine					1		500.00
Rail Mount	ORIEL	1161	A22	CAT	155.00	1	155.00	
Optical Slit	Rolyn	70.1505	48	CAT	229.85	1	229.85	
Slit Mount	Machine					1		100.00
Galvo Driver	Bulova	PA	Data	Verb	675.00	1	675.00	
Miscellaneous				EST			375.00	
							$5028.85	$1000.00

ASSEMBLY A2A5 TEST LENS J19

ITEM	VENDOR	MODEL	PG.	QUOTE	PRICE	QTY	PRICE	MACHINING
Test Jig	Machine							1250.00
Jig Mount	Machine							50.00
Locator Translator	VELMEX	B4016P20J		Verb	572.00	1	572.00	
Translator Mount	Machine							50.00
Rotational Translator	Ardel Kinematic	RTM-175	7	CAT	655.00	1	655.00	
Translator Mount	Machine							50.00
Focus Translator	VELMEX	B4012P20J		Verb	572.05	1	572.05	
ASSY Bracket	Machine							100.00
Rail Mounts	ORIEL	1078	A16	CAT	64.00	2	128.00	
Motor	Superior Electric	M092-FD08		Verb	156.00	2	312.00	
Misc. Electric							500.00	
							$2739.05	$1500.00

ASSEMBLY A2A6 IRIS ASSEMBLY

ITEM	VENDOR	MODEL	PG.	QUOTE	PRICE	QTY.	PRICE	MACHINING
IRIS	ROLYN	75.0460	51	Verb	29.18	1	29.18	
IRIS Mount	Machine							50.00
IRIS Posit.Translator	VELMEX	B4020P20J		Verb		1	599.25	
Translator Mount	Machine							50.00
Coordinate Translator	VELMEX	Custom		Verb	2000.00	1	2000.00	
Translator Mount	Machine							50.00
Upper Light Shield	Machine							50.00
Lower Belows	Fabricate							200.00
ASSY Bracket	Machine							100.00
Rail Mounts	ORIEL	1078	A-22	CAT	64.00	2	128.00	
IRIS Venier Translator	VELMEX	B2512P20J		Verbal	416.15	1	416.15	
Translator Mount	Machine							50.00
Motor	Superior Electric	M092-FD08		Verb	156.00	1	156.00	
Miscellaneous							500.00	
							$3828.58	$550.00

ASSEMBLY A2A7 FOLDING MIRROR ASSEMBLY

ITEM	VENDOR	MODEL	PG.	QUOTE	PRICE	QTY	PRICE	MACHINING
Mirror	Klinger	Custom $\lambda/4$		Verb	1000.00	3 ea.	3000.00	
Mirror Mount	Klinger	Custom		Verb	600.00	3 ea.	1800.00	
Bracket	Machine					3		300.00
Rail Mount	ORIEL	1078	A16	CAT	64.00	3	192.00	
							$4992.00	$300.00

ASSEMBLY A2A8 BEAM SPLITTER

ITEM	VENDOR	MODEL	PG.	QUOTE	PRICE	QTY	PRICE	MACHINING
Beam Splitter				Eng Est.			1000.00	
Splitter Mount	Machine			EST				500.00
Splitter Bracket	Machine			EST				50.00
Rail Mount	ORIEL	1078	A-16	CAT	$64.00	2	128.00	
Misc. Elect.				EST.			250.00	
							$1378.00	$550.00

ASSEMBLY A2A9 COLLUMINATOR

ITEM	VENDOR	MODEL	PG.	QUOTE	PRICE	QTY	PRICE	MACHINING
Colluminator Lens	Space Optics	OAP-18-03 -06	16	CAT	2260	1	2260	
Lens Mount		MM H-6	16	CAT	1195	1	1195	
Mount Bracket	Machine							150.00
Rail Mount	ORIEL	1078	A16	CAT	64.00	1	64.00	
							$3519.00	$150.00

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